Power development and movement ability in junior athletes

Ian McKeown

BSc (Hons) in Sport, Exercise and Leisure with Diploma in Industry Studies
- University of Ulster, Jordanstown, Northern Ireland

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University of Canberra, Australia

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Australian Institute of Sport

Strength and Conditioning
Australian Capital Territory Academy of Sport

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Abstract

The ability to express power is considered one of the main determinants between successful elite athletes and sub-elite athletes. Information regarding the nature and magnitude of strength and power adaptations in pre-elite athletes is less comprehensive than the information available on elite athletes. In addition to power, practitioners reasonably assume that movement ability is strongly linked to performance, but this quality has been largely overlooked in the performance research. The overall aim of this thesis is to provide a basis of research to examine the influence of movement ability on performance outcomes into the future. To achieve this longer-term aim, a series of studies were conducted, beginning with an information gathering study that was designed to provide context to the thesis by investigating the current practices for strength and conditioning coaches and sport scientists working with junior athletes (Chapter 3). The survey responses highlighted the need in high performance sport for more investigation into training methods for junior, pre-elite athletes and to ensure the research outcomes provide practical coaching application.

Based on this need, an examination of the typical response to strength and power training as junior athletes enter a high performance sport program was conducted (Chapters 4 and 5). Substantial improvements in power were observed within 10 weeks in three separate athlete cohorts. These improvements are similar or greater in magnitude to improvements seen in elite athletes over years of training. A recommendation arising from the time course analysis in these studies is that in order to provide comprehensive training analysis, frequent assessments (weekly or fortnightly) of a range of strength and power characteristics should be performed.

The results of the survey (Chapter 3) also suggested that movement assessment tools presented in the scientific literature do not meet their needs since most rely on modified versions of these tools. A lack of standardisation within this realm limits the potential for examining and understanding how movement ability impacts performance. To understand this relationship of movement ability and performance, it was therefore considered important to develop a movement assessment tool which meets the needs of practitioners. The Athletic Ability Assessment (AAA) was designed as a potential solution to this problem and the first step in investigating its utility was to ensure good reliability which is supported by the results

presented in Chapter 6. It is hoped that further scientific validation of the AAA or other movement assessments tools may prompt much needed investigations where movement ability is considered alongside the appraisal of physical fitness and performance characteristics. The study in Chapter 7 provides preliminary evidence for a relationship existing between improvements in movement ability and physical performance, however much more evidence to confirm this relationship in the wider sporting context is required. The research conducted in this thesis is part of the initial steps toward validating the importance placed on movement ability in junior athletes and indeed, senior athletes. This body of work addresses the need for more scientific evidence for the conjecture placed on movement assessment and training at present. Although it is acknowledged the research does not answer all the questions it is the vital first step towards this. Future research can be based off this initial work and shows the importance of this thesis in the context of providing a worthwhile contribution to the field of strength and conditioning, as it attempts to consolidate its footing in applied sports performance science.

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Chapter One

1. Introduction

1.1 Thesis Rationale

The ability to move athletically and with power is essential for sports performance and an area of great importance in strength and conditioning. The development of these key physical qualities is the cornerstone from which physical training for performance enhancement is based. Understanding power development and movement is crucial in junior athletes. If these qualities (the ability to move well and powerfully) are developed appropriately during this important stage of an athlete's development, the athlete will in turn have developed a strong foundation in athleticism from which to train and compete at senior level. This is the basis of the recommendations set out in long-term athlete development models (6, 56, 121).

It is crucial that power and movement ability are understood during adolescence and early adulthood as competing demands for early success may have starved junior athletes of an appropriate training background and exposure to wide variety of sporting skills (11, 77). The popularisation of early specialisation in sports has led some junior athletes towards early success and a very specialised skill-set which they are unable to sustain into adulthood as the demands of the sport overcome their body's ability to cope with the load in training and competition (35, 89).

To combat early over-specialisation in one skill-set, long-term athlete development models offer key recommendations including the development of a range of fundamental skills and foundation movements before sport specialisation later in their development(6, 121). Developing and enhancing foundation movements and fundamental skills in junior athletes is often then the responsibility of the strength and conditioning coach as part of their training program. Foundation movement and fundamental skills commonly include the skills of running, hopping, jumping, throwing, landing and striking through the ability to squat, lunge, push, pull and brace in multiple directions and multiple planes (95). Assessment of the underlying key competencies for athletes to complete these foundation movements and the training thereof shall be defined as movement ability and movement training for the purposes of this thesis. A strong foundation in movement ability is not only a recommendation in long-term athlete development but a commonly accepted concept in strength and conditioning in general (7, 67). The belief is that the foundation of movement can positively impact on the level and complexity of training that each athlete can later be exposed to. This will improve the physical performance capabilities by creating a more robust athlete, with less injury risk that includes improved physical efficiency and thus improved performance.

In many sports improved physical performance is often associated with improvements in power development. Power is a crucial discriminator of success in sport, its importance is reflected in the abundance of scientific investigation in this area (53, 54). Guidelines for developing power in junior athletes are generic at best and tend to focus on resistance training. Strength and conditioning incorporates other methodologies of training (e.g. medicine ball training, plyometric training and sprint training) (7, 67, 96), and should also be considered when recommendations of junior training programs are made. Therefore we must not only focus research on the outcomes of resistance training but aim to better understand how athletes respond to comprehensive training programs that are typical within high performance sport. One major purpose of this thesis is to first understand the training adaptations currently occurring in junior elite athletes through the investigation of power performance in junior elite athletes as they progress through development towards specialisation in one sport at a very high level. This thesis will also provide initial information of a movement assessment tool designed to meet the needs of athletic populations, and investigate the effect of movement training on performance and injury risk in junior athletes. The long-term aim of this body of work is to provide a conduit between the science of physical performance enhancement and the art of coaching to apply mechanical advantages that are the result of sound training programs. The studies presented in this thesis were designed to gain information critical in supporting future research that will achieve this long-term aim.

1.2 Significance of the research

The research studies that comprise this thesis aimed to understand the time course of adaptation of power in junior elite athletes to a comprehensive strength and conditioning program. Frequent measurement of jump performance in junior athletes will provide more detail of the nature and magnitude of the changes typically observed when first entering a training program for the first time, which is previously unreported.

Along with examination of the power adaptation in junior athletes, a novel movement assessment tool is introduced that aims to meet the needs of the coaches working with athletic populations. At present the Functional Movement Screen (44, 45) dominates the research literature however anecdotal evidence suggests it is not utilised within high performance sports programs to the same degree. An outcome of this thesis is to explore an alternative movement assessment protocol. Reliability of the methodology will be presented along with guidelines for future research into this area.

The findings from the research studies undertaken during the doctoral studies have the potential to provide coaches of high performance athletes with a specific movement assessment tool that considers the demands of athletic populations and meets the need for in depth feedback for coaching purposes. Understanding of the adaptation of power variables from training provides reference values using best practice methodology for assessment of power. The sum of this thesis will provide a basis for further work that should be carried out to improve our understanding of the adaptation process in junior athletes. Incorporating the knowledge gained from the studies included in this thesis regarding the assessment and development of power and movement ability may provide optimal conditions for performance enhancement in this crucial population of potential elite athletes in the future.

The aims of the thesis are to:

1. Describe the current practices in long-term athlete development of high performance practitioners with special consideration to power and movement assessment and development in junior athletes (Chapter 3).
2. Describe the time-course of adaptation to strength and power training when entering a high performance sport program (Chapter 4 and 5).
3. Introduce a new method of assessing movement ability and present results for the intra- and inter-rater reliability (Chapter 6).
4. Quantify the magnitudes and time course of the changes in athletic performance characteristics of junior athletes in relation to movement training (Chapter 7).

1.3 Thesis Structure

This thesis is submitted in the form of a series of published papers. The current chapter introduces the topic area of the thesis and provides the rationale behind the need for further examination. The following chapter provides a review of the current literature surrounding power development in junior athletes and also reviews the current understanding of movement ability assessment. Chapter 3 provides context to the thesis by providing information regarding current practices in high performance sport along with recommendations for research supporting these practices from professionals working with junior athletes. In order to tie the concepts of power development and movement together into a coherent process, we must first examine the typical traits exhibited in junior athletes. The time course and magnitudes of adaptation to training in elite junior athletes are described in chapters 4 and 5. To meet the needs of athletic populations regarding the purposeful assessment of movement, a new method of assessment is introduced and examined in chapter 6. Chapter 7 involves the amalgamation of power and movement assessment in one study, assessing the changes in power performance and movement during an intervention study aimed at improving movement quality in junior athletes. The final chapter of this thesis will provide a discussion and synopsis of the findings within the studies including recommendations for future research and practical applications of the findings.

Chapter 3 has been published within the period of candidacy; chapters 4, 5, 6 and 7 have all been submitted for publication and are presently in the peer-review process. These chapters (chapters 3-7) are presented in this thesis in the format required for submission to the journal they have been submitted. A complete list of references for the entire thesis is provided at the end of the thesis.

Chapter Two

2. Literature Review

2.1 Introduction

Junior athletes present a unique set of issues in sports preparation and performance and as such provide a difficult challenge for sports coaches and strength and conditioning coaches. Junior athletes are defined as late adolescent and young adults for the interests of this review. The early identification and development of talent is seen as crucial for future success most sports (89). Therefore there is a great desire in sports development to nurture talent through this tumultuous time period and prepare them for future sporting success at senior level. Precocious performers may already be competing against seniors in some sports. Athletes who have reached this level will most likely have specialised in one sport and are exposed to strength and conditioning for performance improvements for the first time without prior experience of this type of physical preparation. This particular band of junior elite athlete provide a time period that is largely unexplored in the literature presumably due to the assumption that research relating to adolescent or childhood subjects, or adult populations is applicable to this particularly complex period in growth and development. The individual nature of growth and maturation patterns means the application of this research may be unfeasible (89). It should also be considered that even if junior athletes are physically mature, with an older biological age, their training experience will typically not be any different. . Therefore their adaptation pattern will vary from senior, experienced athletes, this is often left unconsidered.

The influence of maturation and the impact of growth factors provide an environment for optimal growth in physical performance (183). The periods when the influence of maturation and growth are strongest in development are generally identified around the age of peak height velocity (PHV). The age of PHV is generally accepted to be early in the teenage years, earlier in females than in males (183, 184). By the time athletes reach the elite performance end of the athlete pathway, the optimal periods of growth will typically have already passed. Therefore guidelines for training around the time of PHV are generic and encourage the development of a wide range of sporting skills (6). There is a body of knowledge in the literature identifying best practice of how to develop potential athletes (6, 56, 89). Often best practices are not in place within sporting pathways although formal recommendations may be in place. This can lead to talented athletes at the cusp of senior training and competition but having not been exposed to the applied theory behind best practice. Instead of developing a strong foundation of sporting competency, some athletes may be striving for immediate success at the expense of this foundation (10, 11). This is a coach education and governing body issue. This review will not concentrate on the time period encompassing PHV where fundamental skills are recommended to be put in place. Research into this area has been well disseminated (16, 95). The pretext to this thesis is the enhancement of future elite athletes. Elite sport cannot necessarily afford to influence too deep or too far down the pathway due to a lack of resourcing and concentrating on immediate or forthcoming competition. Although it can influence down the pathway by pioneering best practice providing practical examples that can filter through the system. In some ways coaches in elite sport have to deal best with the chosen athletes they are given. Although we understand and empathise with the difficulties of development of youth, this review will focus on the subsequent period in development where junior athletes specialise in sport. The concept of accelerated periods of adaptation is as not well accepted (75) however better optimisation of this concept could have potential effects on the end-of-development stage that is the focus of this thesis and will therefore be critically reviewed in this text through identification of when sensitive periods may arise and how current training has influenced this period.

In order to develop along the athlete pathway, athletes will be required to train and compete at progressively higher levels. Power is considered fundamental to successful performance of many sporting activities and is one of the key athletic qualities that training programs will aim to develop (61, 168). For this reason the development of power has been investigated thoroughly in the literature (53, 54, 61). The literature tends to focus on the prescription of load and modalities of training to optimise the mechanical power output of athletes (53, 54). It is a commonly accepted concept that in order to develop power there must be a strong foundation in strength (49, 50). The main training modality used to maximise strength and power qualities is resistance training. Resistance training for strength and power has typically included Olympic weightlifting movements and derivatives there-of, strength-lifts such as the squat, deadlift and bench press, including the use of various rep ranges and variations of the lifts and elements of plyometric and sprint training (54). A well-developed strength and conditioning program will include components across the strength and power continuum at appropriate stages of the preparation plan for competition.

Strength and conditioning coaches will attempt to utilise the various modalities recommended in the literature to enable transfer to sports performance, but the ability to move well and move competently to perform is essential (42) and often not examined in sports performance literature. Athletes need to be able to perform the underpinning movements of sport techniques, to master those techniques whilst also preventing overuse injury (43). In order to prevent injury and enhance performance, strength and conditioning coaches are able to assess the key fundamental movements of sport and highlight any dysfunction (44, 45, 79). Any identified dysfunction is then a focus of training and therapy to enable future development of the movement pattern under stress in order to train for future performance enhancement. The importance of movement ability on future performance enhancement is high; therefore the ability to assess and train movement along with the common modalities of resistance training, and the components mentioned previously, is essential. The link between these two concepts is often anecdotal or general in nature. There is little evidence to date to support the improvement of movement ability and its' effect on sports performance or injury incidence (130, 161). Despite the lack of evidence to support this notion it is a widely accepted training concept in strength and conditioning professionals.

Long term athlete development models are the theoretical concepts that recommend best practice in developing youth along the development pathway towards sports success or alternatively a healthy active lifestyle in adulthood (6). Long term athlete development models support the strength and conditioning concept of nurturing a strong foundation in fundamental movement skills early in development to enable future enhancement of performance (121). Coaching strong fundamentals of movement and training fundamentals including weightlifting, running, throwing and jumping are recommended in the position statements of professional strength and conditioning associations (7, 67, 149). The development of a strong foundation of fundamental movement skills will enable athletes to train for performance enhancement in sport; including components such as strength and power (6).

Power development in junior athletes is not a well explored area but an area interest in strength and conditioning and sports coaching (83, 133, 172, 180). It is the aim of this review of literature and the subsequent thesis to provide an insight into power development and the importance of movement assessment and training in junior athletes for future success in sport. It is critical to get the first steps of athletic development correct, therefore the motivation behind this thesis and literature review is to examine what is known in this tumultuous period in development and how can future research improve our understanding of adaptation to training. This will provide key practical applications that can enhance physical performance in this talented age group, namely the development of movement assessment and therefore the subsequent establishment of strong fundamental movement patterns for future performance enhancement.

2.2 Power

Maximal power in explosive strength movements is often used to assess an athlete's power output (53, 121). In the applied setting of sports performance, 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 (53). This part of the review will focus on the measurement of power as typically described through motor performance tasks such as jumping, throwing and running (36). The measurement of other qualities of power have been investigated in the literature, in terms of physical preparation, power is commonly associated with explosive strength activities, synonymous in the literature with jumping, throwing and sprinting. Power in this context is typically measured using mean or peak power, rate of force development, impulse, or mean or peak velocity; to name a few variables. Measurement of these variables depends on the equipment available and the nature of the performance to be measured (47, 53, 187). Anaerobic power and short-term power capabilities of junior elite performers have been investigated previously (5) and will not be considered in this review. This section of the review will discuss the rationale of measuring power performance, the identified periods of accelerated improvement in performance and the trainability of power in junior athletes.

2.2.1. Rationale

Power values have previously been reported in the literature by means of describing the typical values that can be expected in specific populations. These reference values typically involve reporting changes in jump height of various jump types during assessment but can also include mean and peak power, velocity, and force (4, 179). Power measures have been used to help identify talented athletes in particular sports. At senior level, across sports, the ability to produce power can predict which level of competition each athlete can possibly attain (36, 83, 169). Player profiling in professional sports academies such as in soccer has been able to provide a group of reference values that typify the characteristics of elite junior soccer players and to differentiate between playing positions (36, 70, 118, 128, 162). The results across all these studies suggest that selection bias is evident towards early maturing players. Anthropometric and fitness assessments can play a part in determining who shall proceed to higher achievement levels (118). Levels of fitness in junior athletes are largely influenced by biological maturity therefore any prediction of maturation status can help inform coaches on selection not only in the immediate game but for future long term planning (34). To combat against the exclusion of late developing players, this method can also be used to give more time to develop the gifted performer who does not yet have the physical attributes to compete in chronologically determined age-group competition.

Often studies are cross-sectional or linked longitudinally in design and although they provide valuable information and reference values for future talent identification and development they do not describe changes in power in relation to training (29, 83, 170). Measurement of power in its different forms can aid in talent identification and development. Power and explosive strength qualities may also be measured through more than one mode, the interaction between each method of power development can help to inform coaches of the power profile of each athlete. A profile of different abilities will not only provide more the information for future reference values in talent identification but can be used to identify areas of weakness in strength and power in an individual athlete that can be addressed in future training programs. Identifying and addressing deficiencies in an athlete's strength and power profile can prove a very efficient method of applying testing with practical coaching solutions (51, 131, 151).

2.2.2. Periods of accelerated improvement in power

The measurement of power, along with many other performance tasks, in children and adolescents have enabled the identification of broad periods of time (age) that particular tasks improve more than others (183, 184). In order to understand any subsequent training adaptation, such as during later stages of adolescence and early adulthood, it is important to first explore the interaction of any previous influences on performance. Long term athlete development revolves around the systematic progression of skills training and the eventual specialisation in sports competition (56, 59). Some models of long term athlete development have included and adapted this concept of understanding and taking advantage of any accelerated periods of development (19).

Longitudinal studies confirm the presence of two periods of accelerated development between the ages of 5 and 18 years (150, 184). The first period is from 5 to 9 years. The second period is associated with sexual maturation. Increasing hormonal changes occurring during this period play an increasingly important role during this time (69). During puberty, where sexual maturation takes place, the entire endocrine system is altered. Growth, thyroid, and adrenal hormones are involved in the maturation process. The activation of the hypothalamic-pituitary-gonadal axis that induces and enhances the secretion of the ovarian and testicular sex hormones that are responsible for the profound biological, morphological and psychological changes that occur during puberty (150). This secondary period of growth aligned to sexual maturation creates variation in relation to chronological age between boys and girls. This period is reflected in the accelerated development of speed, explosive strength and aerobic endurance (183, 186) along with increases in muscle cross sectional area (69). From the review of studies by Viru the accelerated improvement of muscle strength appears in boys from 13 to 16 years and girls from 10 to 15 years (183). Explosive strength appears to improve further between 12 and 16 years for boys and 9 to 13 years in girls (183). The earlier periods reported in girls illustrates their earlier sexual maturation. Interestingly strength, in both sexes, referring to the age periods of accelerated adaptation by Viru explosive strength appears to develop before strength. This is counterintuitive to what is commonly accepted in power development where strength must come first before power. The discrepancy in the age periods progression of the strength qualities is possibly the artefact in the data of the combination of multiple longitudinal studies and a reflection of the methods used to measure these qualities and not a potential new model of strength application in children and adolescence.

The use of chronological age to identify key periods of growth and setting developmentally appropriate training and competition based on age does not account for individual maturation tempos or timing. The use of PHV , the period of time when growth of standing height is highest, has been used to differentiate early, late and on-time maturers (29) and provide an indication of biological age as an alternative to chronological age. Using PHV as a marker indicating maturity, studies has found that peak improvement in strength is around 0.5 to 1 year post-PHV in both boys and girls. Increases in jump performance have also been found to occur in this first year post-PHV (183).

Use of predicted age of PHV by Mirwald (2002) (137) is a non-invasive technique using measures of standing height, sitting height, age, and body mass to calculate maturity offset value (years from peak height velocity) (124). This technique of determining biological maturity in youth populations has provided some useful insights into the development of the underpinning characteristics crucial in sports performance. Although there is still work to be done in the area of identification of the key maturation events in development (127). Lloyd et al (2011) have particularly utilised this method of predicted age of PHV to describe the periods of accelerated development of the stretch-shortening cycle (SSC) and the influence that maturation can have on different jump performances (122-124). The largest differences in mean countermovement and squat jump height were between groups in aged 10 y to 11 y and between ages 12 y to 13 y (123). The work of this research group has been able to provide evidence that almost certainly windows of adaptation may exist for squat jump and countermovement jump; however drop jump may follow a different trend, creating a point of difference between slow-stretch shortening cycle (SSC) and fast-SSC capabilities (123). Further research is required into the potential benefits of training for SSC development during these identified periods of time. Reference to biological age is important when describing the changes in young junior athletes as maturation may have a significant bearing on the performance capabilities of the athletes. Lloyd et al (2011) provide examples of the usefulness of including biological age descriptors in research (123). This work has been seminal in attempting to discover more regarding the influence of maturation on the mechanisms behind physical performance with particular reference to the stretch-shortening cycle. Work needs be carried out investigating training adaptations in relation to biological age indicators such as predicted age of PHV over longer periods of time (120, 123, 124).

2.2.3. Periods of accelerated improvements in junior athletes

Periods of accelerated development have been determined in the longitudinal literature to date by Viru and colleagues (183, 184). These periods are identified to occur early in adolescence, parallel to sexual maturation. Junior athletes will have progressed past these natural periods of development. The next stage in the development is of interest in elite sport as the late teenage years is when practitioners in high performance sport tend start to influence training; this will vary between sports. Dupler et al (63) collected data from a state American high-school football combine, grouping athletes by school year and position. As expected, differences according to school year and position were evident. Significant differences were found between school years 9 and 10, and 11 and 12 and across the positions the players normally play. This data suggests that there are still significant differences in these school age groups and possibly further significant changes in performance can be observed in junior athletes towards the end of adolescence. Although the changes reported are not of the same magnitude as the earlier acceleration in performance. This has implications for the importance of optimising this age groups' physical development and not relying on earlier periods of maximum accelerated development, typically caused by the advent of sexual maturation. Training must be well designed and thoughtful consideration of each athlete's development must be included.

Not all evidence supports the suggestion that performance will improve with chronological age and therefore with maturation. Ingebrigtsen (2013) reported that the comparison between U16 and U18 in physical performance tasks (countermovement and squat jump) does not support the hypothesis of pubertal development and muscle growth leading to increased performance through adolescence (107). This study did not differentiate between male and female subjects and the age groups used in the study are theoretically too old to compare the accelerated periods of performance as identified in previous research (183, 184). This study does however; interestingly suggest maturation alone will not improve performance, greater need for targeted and sequential training to ensure appropriate development. The author recommends that the use of frequent testing to assess performance could increase the coaches understanding of the current group, highlight weaknesses and identify potential areas of improvement (107).

The findings from Dupler et al (2010) (63) and Ingebrigtsen (2013) (107) support the investigation into the training adaptations typically occurring in late-stage adolescent and junior athletes; athletes who are considerably post PHV but not yet adults. No periods of further accelerated growth have been identified via ontogenetic development therefore the guidelines of training and power development have been the same as for senior athletes. However are they developmentally appropriate? Can junior athletes be exposed to the same complex training as senior athletes? Are the improvements similar to those seen in untrained athletes or should further considerations be explored?

From the general trends shown in both junior males and females, periods of accelerated growth have been identified for strength and power, and indeed other physical qualities of athletic performance such as aerobic and anaerobic power and flexibility. The advent of the identification of these critical periods of accelerated development has produced some intriguing work into the theory that further training of these specific physical qualities during specific time periods in chronological age can further improve these qualities. This is the basis for the windows of adaptation concept coined by Balyi in his LTAD model of long term athlete development (18, 19, 21). This theory is not without its controversy in the literature and has been closely scrutinised in recent years (75). Further work is needed into the best training practice in the years past the proposed critical periods of development in order to best improve physical qualities before the demands of senior competition and training are required. As mentioned previously Lloyd's research (123) and proposal of the Youth Physical Development model (YPD) (121) has expanded on the previous work of Balyi and provided a current and applicable model of physical development for young athletes. Other models have been proposed from other disciplines within sports science such as the Developmental Model of Sports Participation (DMSP) (56) and the Foundation, Talent, Elite, and Mastery (FTEM) (92). The aim of each of these models is to provide a framework or pathway for young athletes to appropriately develop physically, emotionally, and technically.

2.2.4. Trainability

The critical periods of accelerated development of performance of strength and power qualities as suggested by Viru (12-16 y in boys and 9-13 y in girls) are brought about by the naturally occurring interaction of neuromuscular and biochemical properties during sexual maturation (182-184). Training may optimise the potential extra androgens circulating in the body improving on the ontogenetic effect of development on sport performance (12, 94). Taking advantage of these is the basis of some long term athlete development models (19, 20) creating periods of accelerated adaptation, however this concept is still to be confirmed with satisfactory empirical evidence (75).

Longitudinal studies have provided timeframes of when physical performance improvements are likely to occur (183, 184). These long term studies' time points of collection are typically per year and do not provide an insight into the typical training adaptation expected during this complex period of growth and maturation in junior athletes (28, 30). Training intervention studies have reported improvements in power values, including jump height during childhood and adolescence (183) but many tend to report pre and post-only values.

2.2.5. *Resistance training*

During adolescence, Harries (2012) reports statistically significant improvements in jump height ranging from 5.1% to 24.6% following resistance training (96). The smallest improvements are seen in studies were the resistance training progression of load was not individually adjusted (96). The studies with larger improvements did adjust for individual adaptation to the training program (96). These findings suggest that if improvements are to be sought in training interventions individual progression of load must be accounted for. In senior athletes this can be accounted for by utilising the measurements of strength and power testing and diagnosing areas of weakness that can be addressed by changing the training stimulus (52, 54, 151). Resistance training guidelines for youth as recommended by the National Strength and Conditioning Association (NSCA) and the Australian Strength and Conditioning Association (ASCA) both state the importance of a properly designed and coached training program and that by following the guidelines motor performance can be enhanced and contribute to sports performance in youth (7, 67).

Improvements in jump height of between 5.1% and 24.6% as reported by Harries et al (2012) in a meta-analysis of power development in junior athletes is within the range reported by the work of other training studies. Vertical jump height improved significantly (9.7% ± 7.9%) in junior rugby league players in a supervised strength and power training program over 12 weeks (60). Junior basketball players in a supervised program of strength and conditioning also report gains in vertical jump height (5.4% ± 2.4%) (114). Interestingly both these studies report smaller improvements in unsupervised groups of the same training program, or using online video resources (114). Adult populations also show a greater rate of training load increase and maximal strength gains compared to unsupervised (129). These results support the recommendations of the strength and conditioning associations in relation to close supervision and coaching of junior athletes. Improved strength changes can also be made in junior athletes with supervised strength training compared to sport training only (110). Keiner, (2013) reports soccer player strength in back and front squat does improve with age from under 13 through to 19 y, and strength values are higher in strength trained players versus a control group of soccer only training (110). Keiner has provided evidence that strength does improve and consequentially power performance in junior athletes and that these improvements are greater when sports training is supplemented with strength-based training. The point that strength training can further improve performance than sports training alone was also one of the conclusions from Ingebrigtsen using male and female handball players (107).

2.2.6. Optimal methods and loads

Strength training has shown a positive relationship with power performance (52). To ensure optimal gains are made in training, training methods for maximal effectiveness are commonly examined (54). Similar to the use in senior athletes an optimal load for power development using resistance training has been explored in children and youth (67). The use of training modalities such as plyometric training, sprint training and medicine ball exercises have reported improvements in power capabilities of junior athletes previously (67, 96). Dayne et al (2011) (62) also investigated the use of optimal load for power development in junior male athletes using jump squats. The optimal load during later stages of adolescence is still considered to be at bodyweight-only even when maximal strength capability is accounted for (62). This is different to senior, well-trained athletes where loads of 42%-62% of one repetition maximum produce peak power values for bench throws and provide the guide range of loads for optimal power training (8). The optimal load for power production in an exercise is largely dependent on individual strength levels, the training experience and the sport of subjects involved in the study (50). The use of bodyweight jump squats for optimal power production provides strong recommendations for future training in junior athletes however this study provides no training intervention in the design, only when maximal power output was measured. Bodyweight training and plyometric training (including bodyweight jump squats) in juniors has previously been endorsed and is a logical starting point for later more complex training (143). Further investigation into the optimal load for power development and also transfer to sports performance should be explored in the future for junior athlete populations. This information will progress the body of knowledge involving junior athletes preparation for future success.

2.2.7. *Timing of resistance training*

Although results are promising for the inclusion of resistance training for junior athletes for increased power development, the timing of the inclusion and the loads used to elicit improvements is an area of much conjecture in the literature. In-season competition may have a detrimental effect on vertical jump performance in junior athletes. This is similar to senior athletes where long term improvements are reported however during periods of competition the magnitude of the improvements is attenuated (167). Junior female soccer players have reported no improvements in bodyweight vertical jump height during a four-month season whilst continuing strength training (126). Vertical jump height with an external load of 20 kg and squat strength did significantly improve. The authors account for these results by suggesting that a learning effect was present and that optimal loads for bodyweight vertical jump were not trained during the intervention period and therefore didn't improve. However strength training was constant throughout the intervention and therefore strength did indeed improve (126). Increase in power with resistance training is not guaranteed. A decrease in vertical jump performance in junior rugby league players has also been reported. Under-18 players' vertical jump height did not increase with 10 weeks of training however speed and agility scores did improve (84). Improvements in bodyweight and skinfolds along with the muscular endurance-type training utilised suggest that although body composition improvements may improve speed and agility scores, explosive strength or power may be affected by this type of training; more intensive strength training is required to maintain maximal strength. Training was performed using machine weights and submaximal loads suggesting that future studies should incorporate free-weights and optimal load prescription. This type of conservative training methodology has been recommended previously and although applicable for general populations may be inadequate for athletic populations (7, 67). Future work should use talented athletes to investigate the effectiveness of interventions. Intriguingly the under-15 group exposed to the same training did not show the deleterious trend in jump performance (84).

Competition phases may not always equate to decreases in jump performance. A 16-week longitudinal study of female under-19 volleyball players showed 8.7% improvement in jump height between the preparatory and competition phase of the season (164). Similar significant improvements are observed in other jump performance variables measured during this trial (164). However the testing did not examine the difference between the start and end of competition but between the start of preseason and end of competition.. The pre and post testing used in this study encompass both phases and does not delineate the effect between the two phases. For future research more frequent testing could assess the time course of the adaptation during preseason and describe any drop off during the competition phase with greater resolution.

Short training interventions of four to six weeks have also shown significant improvements in jump performance in junior athletes (81). Four weeks of judo training in preparation for a tournament, youth athletes observed significant improvements in sports specific testing and jump performance (81). Judo training incorporated bodyweight strength exercises and upper and lower body plyometrics. The adolescent group (mean ± SD; 15.3 ± 2.0 y) increased vertical jump power significantly by 26.7% and sport specific testing by -5.9%, showing a performance improvement with lower heart rate response to throwing task. Interestingly the "child" subject group (9.9 ± 1.6 y) only improved in sit and reach flexibility (10.2%). The sport specific test (Special Judo Fitness Test – SJFT) used in this study simulated a judo contest including intense bouts of throwing with short rest periods (76) . This younger group was presumed to be between periods of accelerated development (81). No reference to biological maturity is made in this research and is a significant limitation of the literature. This study does provide encouraging support to the longitudinal research into the periods of accelerated development, and supports the assumption that appropriate training can further increase performance characteristics. The nature of the sports training may indeed explain the improvements here compared to other studies of sports training only (107). The promotion of youth exposure to a wide range of sports is part of the recommendations in long term athlete development models (56, 121). The magnitude of improvement in vertical jump power reported by Fukuda is not supported by Hammett (2003) (93) who reported only 2.4% improvement in vertical jump power after four weeks of intensive training in male football and female softball players. Training included weight training (three days per week), agility (two days per week), plyometric training (two days per week) and sprint training (two days per week). Bodyweight and anthropometric characteristics did change significantly in the 4 weeks. Improvements made early (between week 0 and week 3) were significant for power values suggesting neurological adaptation influence initially after 3 weeks is not maintained for 5 weeks (93). There was no distinction or comparison between male and female subjects in the study.

A limitation of these studies is the measurement protocol used for jump performance assessment. The use of a jump and reach test rather than the more sophisticated measurement systems for jump performance that are now readily available that may have provided more insight into the performance capabilities of the subjects if utilised. These systems include the use of linear position transducers, force plates, and accelerometers (48, 187). Frequent assessment of the time course of adaptation to the training program will also add to the insight gained from such studies in junior athletes. Most of the study designs to date use pre and post –test analysis.

2.2.8. Injury prevention training

Well-designed training programs will include elements of performance enhancement and injury prevention. Therefore to discuss power training, particularly in juniors it is important to also consider its' effect on injury risk. Neuromuscular training has been proven to reduce the likelihood of injury, particularly non-contact injury (2). Non-contact injuries, and anterior cruciate ligament rupture, in particular can be catastrophic to junior athletes. Female athletes have been shown to be at higher risk of this type of injury (73). It has been proposed that this is due to sex differences in neuromuscular development during maturation (144). To combat the deficiencies in motor tasks commonly associated with injury neuromuscular training programs have been developed (148). Neuromuscular training will include elements of strength training and other methods, such as low level plyometrics and balance training to improve motor control of subjects. In describing the changes in injury risk during interventions, performance outcomes are also typically measured (155, 156). Typical improvement associated with neuromuscular training is comparable to strength training alone (60, 155). Although a method described in the literature, neuromuscular training in junior athletes should be considered sound strength and conditioning practice (142). Neuromuscular training programs have reported some positive effects in junior athletes for injury prevention and also performance improvement (148). A six-week intervention of neuromuscular training (156), three times per week high school female soccer players have shown improvements in drop jump quality of movement (mean absolute knee and ankle separation), however jump height was not reported. Significant improvement in 2-step approach vertical jump height (3.3%) was observed although the effect size was trivial. No improvement was found in countermovement jump. The results of this study are comparable to a similar study design in female basketball by the same research group (155). Indicating improvements in neuromuscular qualities can be made with training three times per week for six weeks. However vertical jump performance improvement across both studies using a similar training program show only trivial changes and provide inconsistent findings across different jump types. Suggesting further work is needed in this area to incorporate performance enhancement whilst also addressing elements of injury risk for junior athletes.

2.2.9. Conclusion

Investigation into the power capabilities of junior athletes has provided reference values for typical improvements in performance in relation to chronological and, in some cases, biological age. However study design has typically not reported the time course of adaptation in favour of pre- post design. The trainability of power during key periods of development has been observed and suggests accelerated periods of adaptation may occur for some qualities of strength and power such as the SSC but further work is needed into other mechanisms of power. Future research in this area must include descriptions of biological age of the subjects and provide frequent measures to describe the time course of adaptation; this is previously unseen in the literature pertaining to power development in junior athletes. Measurement of power performance must not be abbreviated to only report jump height as the key performance measure and a range of jump types must be included to examine different performance characteristics commonly related to sports performance. Investigation into the performance capabilities of children, early adolescents and adults are reported in the literature. There is a scarcity of research studying the group of elite performers who may still not be fully mature but are potentially preparing for senior level. Late-stage adolescence and precocious performers produce a unique mix of factors contributing to performance; these are not well explored and must be understood. This will aid in the future progress of talent development processes.

2.3 Movement Abililty

In order to effectively apply the underpinning physiological and mechanical advantages of training, as suggested for power development, there must also be a strong foundation of body control and ability to move well with accuracy and coordination. . The importance of a strong foundation in fundamental movement skills is supported by the recommendations from long term athlete development models (6, 56, 121) and position stands for youth training (7, 67).

The functional movements required for sports performance are commonly identified as the foundation movements needed to be built upon for future training and competition demands. The concept of developing these functional movements has been commonplace in strength and conditioning programs for many years. Functional movements will generally revolve around the ability to squat, lunge, push, pull and brace in various planes of motion (42, 43, 87, 88). To perform these movements well will enable athletes to develop sporting skills to the level desired. This systematic progression is one of the key components of contemporary strength and conditioning programming, the level of athlete is irrelevant. The definition of a functional movement is variable depending on the sport and the level of athlete. At junior level functional movements should be diverse and cover many areas, this in line with long term athlete development models' recommendations to develop a strong foundation in a wide range of abilities early in the athlete's development. As athlete's develop and specialise in one sport the functional movements required will narrow but will be required to be at a very high standard to cope with competing demands of training and competition. Although clearly an important element of athlete preparation, the assessment of movement and the relationship between movement and performance is not well reported in performance research. The identification of dysfunction has previously been the domain of the physical therapist and medical officer. The isolated assessment of single-joint flexibility and integrity has been the basis of musculo-skeletal screening (43) and has included other functional tasks such as small knee bend and hop and stop. The inclusion of movement in screening has enabled the strength and conditioning coach to provide a more comprehensive functional assessment of the athlete that is considered more practical and applicable to training considerations in collaboration with medical staff. The inclusion of functional movement assessment allows assessment of the whole dynamic system of the body in motion rather than in isolation (43, 165).

2.3.1. Functional Movement Screening

The introduction of the Functional Movement Screen (FMS) in recent years has enabled a quantification of the key foundation movements in activity (42, 44, 45). This seven exercise screen provides an insight into areas of asymmetry and dysfunction of the body when performing a standardised assessment protocol of typical base-level movements. The results from this assessment inform the coach of areas that need addressing, often this through therapy and corrective exercise prescription.

The FMS proposed by Cook et al (2006) (44, 45) has been the principal guide to functional movement assessment (43). This is evidenced by the lack of alternatives introduced in the literature. The FMS dominates the literature but must not be considered the only viable method of assessing movement, particularly in athletic populations (79, 115-117). The evidence to support the use of FMS as a predictor of injury and predictor of performance is comparatively unexplored and inconclusive. The use of FMS and alternative methods of movement assessment are discussed in the proceeding sections of this review.

2.3.2. Reliability

The initial use of FMS must consider the reliability of the screening under various test conditions. FMS has reported "excellent" level of agreement between averaged scores for novice (n=2) versus expert (n=2) raters using healthy college students. Novice raters had only completed an introductory course to the screening process (136). The results of this study are positive for FMS as it provides convincing evidence that its' rater education program is sound. Intrarater reliability as reported by Gribble et al (2013) used 37 test raters who are athletic trainers of various levels of experience (91). The level of experience has an effect of the level of intrarater intraclass correlation coefficient (ICC) including those subjects with FMS certification. More experienced athletic trainers provide higher ICC values. This indicates a greater level of agreement of scoring between assessment dates of the same athlete's test. This study only reports the total score agreement, further work should include reports of the individual test scores for future reference. The reliability of the FMS process has recently also been investigated using real time assessment (160, 173). Reporting of real time reliability is essential in an applied setting where time constraints and the importance of instantaneous feedback make the use of video assessment extraneous. Real time intersession (ICC 0.92) and interrater (ICC 0.98) reliabilities were found to be high between novice and experienced raters (160). The scoring of four raters of varying experience exhibited intraclass correlation coefficient (ICC) for the total tests scores for test one of 0.89 and test two of 0.87 showing "good" interrater reliability. Further work is needed to incorporate larger rater numbers as assessment will not always be carried out by the same person. With subjective ratings of movement, applicability to other populations and comparison to other athletes can add to the strength of the use of a standardised movement assessment (43). The comprehensive use of one protocol is lacking at present, addressing reliability may counter this

Typically only the ICC have been reported for the interrater reliability (91, 166, 173). This does not provide an indication of the standard error of measurement (SEM) within the screening tests. SEM has been reported in some of the studies to provide reference values of the typical error experienced in this testing protocol however they are not discussed in the papers (79, 114, 160). Future studies should include both values and discuss the practical changes observed between test scores. This is particularly important in any intervention or observational study investigating the influence of functional movement on sporting performance or injury risk.

2.3.3. Injury Risk

Dysfunctional movement as illustrated by poor FMS scores may identify athletes with a higher injury risk. Athletes with poor dynamic balance, asymmetrical strength and flexibility (i.e. poor fundamental movement patterns) are more likely to be injured (112). The FMS has been used to predict injury in various populations. A score of 14 or less on the FMS in professional American footballers (National Football League; NFL) was able to predict the likelihood for injury (112). Positively changing the FMS score in preseason using corrective strategies can aid in alleviating the identified asymmetries and obtain a score greater than 14 (111). Track and field athletes who score higher in the FMS, with no asymmetry and specifically who score well on the deep squat are also deemed more likely to have improvement in their individual performances for the following competitive season (38).The FMS has been able to provide a threshold score from which below this score subjects are more likely to be injured. This is non-specific in identifying the nature of the injury risk thus far and although this is strong preliminary findings there is still more research to be done to establish the FMS scoring and injury risk (80). Secondly, more work is needed to determine if injury risk is reduced when improvements in scores are achieved and asymmetries have been resolved.

Further work into the use of FMS scoring to predict injuries has been carried out in different populations, but has not addressed the improvement in scoring and injury risk. The ability to predict injury agrees with previous work, this time in Marine officer candidates, again a score of less than 14 equated to greater injury risk (119). Lisman included a multivariate analysis of FMS using the standardised Marine Corps physical fitness test (PFT) (pull-ups, abdominal crunch, and 3-mile run). Combining poor PFT scores plus FMS significantly increased predictive injury risk scores, concluding that physical fitness and poor movement ability will increase injury risk. Further investigation is suggested to look at other populations and to analyse the optimum combination of tests to best predict injury. The FMS has been able to assess the effectiveness of a training program designed to improve FMS scoring (80). However, the link between improving FMS total score and sport performance and/or injury risk is still not established, although there is some evidence to support this link there is equally research to suggest more research is needed (130, 161).

FMS may not be able to predict injury conclusively as FMS scoring does not appear to alter when under neuromuscular fatigue (39). Postural control deficits and static balance under fatigue are considered risk factors for injury (39). When put through a fatiguing exercise protocol, subjects' FMS composite scores examined before and after were not related to changes in static balance and may not be useful to predict who will have greater deficits in balance after exercise. This study was conducted on general population, healthy, recreationally active subjects within a wide age range (39). Identification of injury risk must be carried out on athletic populations if professional strength and conditioning coaches and other practitioners working in high performance sport are to utilise this methodology as a valid measure of injury prediction.

2.3.4. Movement and Performance enhancement

Prediction of injury and sports performance has been examined previously. Although to our knowledge there is only one study to date attempting to discuss the interaction of FMS and performance testing on injury prediction and sports performance outcomes. Basketball players tracked over 2 years for specific tests of fitness and movement quality (including FMS) found little relationship between test scores and injury prediction (130). Prediction of performance appears to be linked with a stiffer torso, more mobile hips, weaker left hand grip and a longer standing longer jump. Tests of fitness and movement quality may predict some aspects of on-court performance however this research group suggest more data is needed to fully assess the predictive quality of movement testing on performance and injury (130). This subject group are being studied over a number of years to see if any links exist in the longer term, this research is ongoing (130).

A criticism of investigating a relationship between movement and direct transfer to sports performance is that functional movement may not directly impact on the sports performance but alternately it will impact on the ability to train the underpinning physical qualities of strength, power, speed, agility, etc. these qualities have not been investigated in the context of functional movement screening or other movement assessment tools to date. Cook (42, 43) and other strength and conditioning coaches (86, 87) who promote movement fundamentals are not necessarily hailing movement and functional movement screening scores to have a direct impact on performance. Conversely they are promoting solid movement patterns that do not involve any dysfunction as a platform for sports training, which will in turn improve performance. The subsequent training past the correction of movement and function, into performance enhancement and the interaction of these competition demands is largely unexplored in the research to date (158).

The relationship between performance and functional movement is inconclusive to date. When FMS scoring is compared to typical strength performance in golfers, strength appears to relate better to performance indicators of golf better than FMS (161), however there is no report of injury prediction in this study. The indicator of golf performance was club head swing velocity and this showed a significant correlation to maximal back squat strength ($r=0.805$, $p=0.0001$). As the only measure of golf performance, club head swing velocity performance will be biased towards stronger subjects as they will have the potential to swing the club faster. Successful golf performance is multivariate and the use of only one performance indicator that is biased towards strength and power is not reflective of true relationship that the other measures, including FMS scores, may have on overall performance. This is a large limitation of this study and appears to be biased towards strength performance.

Performance tests of medicine ball throws, agility T tests and single leg squats have been examined to correlate to trunk endurance and FMS scores (158). However the interaction of static and dynamic test in performance is complex suggesting further investigation is needed to adequately determine their impact on performance. Despite the lack of evidence for the inclusion of movement assessment to predict injury and performance it is still commonplace in contemporary strength and conditioning practice. The progressive use of FMS and functional movement training is recommended in junior athletes for their long term development and hopefully future sporting success (121).

2.3.5. *Alternative screening tools*

Movement is not only assessed through the use of FMS. Although this is the most common protocol referred to in the strength and conditioning research. To predict risk from non-contact injuries the use of neuromuscular assessment has been used. This typically involves lab-based biomechanical assessment of joint forces and angles under various conditions (99, 146, 147). The use of drop landing or drop jumping from a height and simulated cutting movements are commonly used to assess dysfunction and identify injury risk (100). These movements are used as they closely mimic the movements where non-contact injury is highest. The field-based assessment of a continuous tuck jump for 10 seconds has provided coaches with an assessment tool with high correlation to the measurements seen in the lab-based techniques (145). Along with the assessment of these movements, training programs have examined their efficacy in improving the outcome variables during landing, jumping and cutting tasks (113, 155, 156). The neuromuscular training programs that are used involve training the movements through strengthening key musculature and improving the coordination involved in these tasks (148). Overall there is an improvement in the injury risk assessment, and in some cases this improvement is coupled with improvement in physical performance tasks such as vertical jump height. The aims of the neuromuscular training programs tend to involve exercise choices only concerning improvement in injury risk and not including sports performance. These studies have predominantly been performed in young females as these are the high risk in this cohort of devastating non-contact injuries (144).The use of injury prediction and inclusion in movement assessment must be examined in other sporting populations in order improve the relationship between movement and performance.

Functional movement and injury risk should be assessed together to inform coaches of the best strategies for future improvement in each athlete. The combination of an injury free and efficient mover, and the subsequent training programs devised to improve these qualities along with sports performance should be the aim of all strength and conditioning programs. To date these appear to have been investigated separately or not including all the parts in the discussion. Future research should incorporate movement assessment and injury prediction that is specific to the demands of athletic populations. The inclusion of potential performance improvement to injury prevention programming may increase compliance to training programs. The inclusion of other tests of sports specificity or neuromuscular control to compliment FMS have been proposed (79, 138) and add credence to the use of FMS in sporting populations.

FMS has provided a strong starting point for future practice however the FMS must not be seen as the only movement assessment tool available. On the other hand FMS is the only one examined in the strength and conditioning literature to any great degree, in order to strengthen the use of movement assessment in performance research and practice, alternate protocols must be proposed and supported with appropriate reliability and validity. It is recognised as a limitation of this critique of the FMS that there is little empirical evidence against its use. Conversely the literature supporting its use is only relatively recent and to propose alternative processes and methods in the research will take a period of time. At present this information is not available and it is the purpose of this thesis to propose the initial steps toward providing this evidence. This will evolve the movement assessment and training methodology to further enhance sporting performance.

2.3.6. Conclusions

It is a commonly accepted concept that a strong foundation in fundamental movements is critical for improving sport performance. These movements, often classified as functional movements, have been recently examined in their ability to predict injury risk and enhance performance. Further work is required to conclusively support the strong recommendations of the importance of foundation movement in sports training. The use of FMS has presented some clarity towards its' practical use in coaching but the FMS is not the only method used to assess movement in high performance sport. In order to develop this area, alternate methods of movement assessment should be proposed and scrutinised against current protocols. Movement assessment and training is typically part of strength and conditioning programs, this area must be driven to have further evidence to support its use and thus being able to be used in mainstream performance research in the future. The consideration of movement ability in performance changes in research is lacking. This is likely to be due to the lack of consistent reporting of assessment methodology in the literature to date. Development of this area can bridge the gap between the science of performance enhancement and the art of coaching as the ability to move well is the conduit between mechanical improvement and transfer into sports performance enhancement.

Finally, of note is the lack of investigation into the impact of FMS in junior athletes. Future work in this area may examine whether movement scoring can be improved early in an athlete's career and the potential added benefit of attaining a strong and robust foundation of movement early. This is essentially the logical progression of training and the topics of investigation in movement in adult populations, surely this should be investigated early in the athlete's life cycle to gain most benefit. The FMS scoring and movement assessment in general in junior athletes has not been well examined even though this is the logical starting point of training foundation, functional movements for future sports performance.

2.3.7. Future Considerations

This review examined the literature relating to power development in junior athletes and the assessment of movement and its' relationship to injury prevention and performance enhancement. The relationship between these two competing concepts of power and movement has yet to be fully explored. Future research providing a conduit between these concepts will not only aid in performance but also reduce injury risk as movement dysfunction can be identified and addressed; producing more robust and high performing athletes. This is particularly relevant to junior elite athletes who have competing demands of physical and sporting enhancement at one time without the prior training background to respond to training as a senior athlete might. Further work is needed to examine the time course of changes in junior athletes in relation to power performance. In relation to movement assessment, this is young field in performance research with only one protocol established in the literature. To improve the standing of movement assessment in performance research and in applied settings further scrutiny of this method is needed and alternative methods should be proposed to address the needs of particular populations. In high performance sport this is yet to be established as practitioners commonly utilise their own modified version of other assessment tools.

Chapter Three

To appropriately further our knowledge in the area of junior athletes and power development it is first imperative to understand contemporary thinking and practice. By investigating current understanding of long term athlete development and what the current practices are in high performance sport, meaningful and applied research can address the gaps identified and investigate areas of particular relevance to these practitioners.

Current practices of long term athlete development of junior athletes in high performance sport environments

Ian McKeown [1, 2, 3]

Nick Ball [2]

[1] Department of Strength and Conditioning, Australian Institute of Sport, Belconnen, ACT, Australia

[2] National Institute of Sport Studies, Faculty of Health, University of Canberra, ACT, Australia

[3] Department of Strength and Conditioning, ACT Academy of Sport, Lyneham, ACT, Australia

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3.1 Abstract

The purpose of this study was to report the current practices and application of long term athlete development theory within elite athlete pathways. Sixty-five strength and conditioning coaches, sport scientists and other professionals participated by completing an electronic survey. The survey elicited information about awareness, understanding and use of common athlete development models. Seventy-two percent of the respondents apply some elements of long term athlete development theory. The most commonly understood model is Balyi's LTAD model. There is awareness of alternative models; however these are not as deeply understood. Additional questions were asked regarding the use of movement assessment and performance testing in junior athletes. All respondents reported the use of some form of performance assessment, with strength and power assessment most common. Movement assessments are also widely used, however no set methodology is preferred with the majority of practitioners using their own modified versions of published assessment tools. The survey shows that within high performance sport there is an understanding of long term athlete development and the various performance and movement assessments that can aid in programming and coaching decisions; however there is a strong desire for further research into these areas and their practical application in the development of elite athletes.

3.2 Introduction

Successful national sporting organisations around the world have adopted a variety of long term athlete development models to provide direction to their coaches' working within the junior sport pathway. It appears that the basis for a large proportion of these plans stem from the popular work of Balyi (13, 14, 17, 20, 21, 24, 26). Balyi's Long Term Athlete Development model (LTAD) is a framework for an optimal training, competition and recovery schedule for each stage of athletic development and is currently acclaimed to be the most relevant and well-known in contemporary coaching. LTAD is proposed as the framework for the proper management of youth and adolescent growth and development processes, and has identified critical periods of accelerated adaptation to training. The model is broken down into 9 stages of athletic development defined by chronological age categories (19). Recently Ford and colleagues (75) argued that there appears to be a number of problems with this theoretical model that are not necessarily transparent to coaches. Principally, the longitudinal or experimental data upon which the model is based is lacking scientific rigor (75). It is also argued that biological age, rather than chronological age, should be used to prescribe training that is relevant to the physical and psychological maturity of each individual (6, 109, 139).

There are a number of alternative models and concepts in the literature that aim to provide guidelines for developing talented juniors into accomplished senior performers (55, 65, 85, 121). Côté's Development model of sports participation (DMSP) is referenced in contemporary coaching texts (56, 58, 59). Côté proposes a trajectory towards elite sports performance consisting of three distinct phases: sampling years, specialising years, and the investment years. As athletes progress along this trajectory they are exposed to wide range of sports and deliberate play activities. Then as they progress through the specialising years they start to compete in fewer sporting activities which include both deliberate play and deliberate practice activities. Finally reaching the investment years where youth typically commit to only one sport and engage primarily in deliberate practice (56, 58, 59). Lloyd's Youth Physical Development model (121) is another alternate long term athlete development model that encompasses athletic development from early childhood up to adulthood. This model provides guidelines for when different fitness components such as speed, agility, power and strength should be emphasised in relation to an individual's biological age and unique rates of maturation and development (121).

At present, scientific research examining the effectiveness of any of the current guidelines for long term athlete development is absent. Recent studies have begun exploring some of the underlying principles, but these types of studies are still scarce (123, 124). More research is available describing the physical and physiological capabilities of successful versus unsuccessful junior athletes (36, 64, 118), however this type of data provides limited information to practitioners who are trying to decide upon which guidelines to use in practice. Of course this lack of scientific investigation should not discount the use of the available long term athlete development concepts, but more research into the effect of the models in the long term is needed to assist practitioners in determining the most appropriate guidelines to employ.

To ensure that future research is influenced by current best practice within the high performance sport environment, the current study aimed to gather information on how coaches currently apply the theory of long term athlete development, assess performance and use movement assessments with junior athletes; to report the current understanding and critical appraisals of existing long term athlete development models from strength and conditioning coaches within high performance sport environment; and to provide future directions for practice and research in the area of long term athlete development and training of junior athletes.

3.3 Methods

3.3.1. Subjects

This descriptive study utilised an online survey electronically mailed to 90 individuals involved in high performance programs across a variety of sports in Australia, Canada, Great Britain, Ireland, and New Zealand. Ethical approval for this study was granted by the Institutional Human Research Ethics Committee. The introductory email, which contained a link to the survey, explained that respondents were consenting to inclusion in the study by completing the survey. The survey response rate was 78% (n=65; male=55, female=10). The majority of respondents identified themselves as a strength and conditioning coach (n=38), with the remainder of the respondents either responsible for sports science (n=8), head of high performance (n=6) or other (n=13). All respondents of the survey reported being actively involved with the development of junior elite towards senior level in some capacity and had all worked professionally within sport across either in professional or non-professional elite sport for a minimum of 2 years. Figure 3.1 illustrates the sport and level of performance each respondent was involved in.

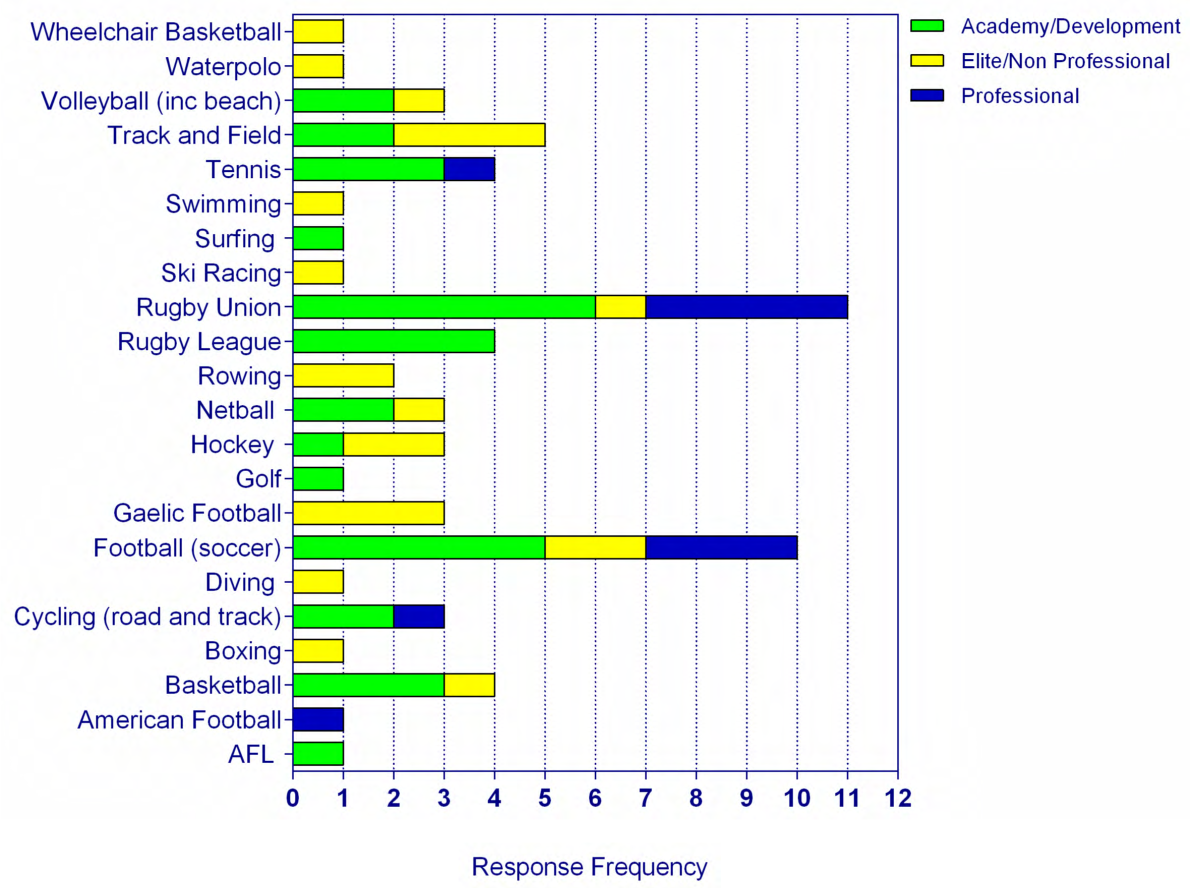

Figure 3.1 - Number of participants representing each sport at various levels of performance. This figure represents the 65 respondents, 15% of whom reported working in professional sport, 34% in elite but non-professional sport and 51% in academy or development level

3.3.2. Survey

The survey was divided into two main sections. The first section examined the participant's level of background knowledge and understanding of long term athlete development models. The questions in the second section focused on the assessment of junior athletes. These questions aimed to elicit information on the usefulness and efficacy of both performance testing and movement screenings in practice. A range of question types were used to illicit the desired level of information. Open ended questions were used when necessary to enable the respondent to provide further information and recall personal experiences, resulting in a more comprehensive collection of information around the critical topics. A copy of the survey questions is included in the appendix (please refer to appendix 3).

3.3.3. Statistical analyses

Frequency analysis for each question was conducted with results for each question presented as absolute values or percentages of answer categories. Answers to certain questions were categorised based upon the key words used in the answer. Subsequent analysis was then based upon frequency analysis and not on qualitative answers.

3.4 Results

Concepts from long term athlete development models were used by 72% of respondents in programming for junior athletes. Of the long term athlete development models the most popular was Balyi's LTAD model (Figure 3.2) with 95% of all respondents aware of the model. Of those respondents 36% indicated an in-depth knowledge with another 53% reporting a good understanding of the model. A small number of respondents reported no understanding (4%) or only a vague understanding (6%) of Balyi's LTAD model. Of the alternate models presented in the survey, 47% of all respondents were aware of Cote's Developmental Model of Sports Participation but only 10% felt they had an in-depth understanding. Lloyd's recently proposed Youth Physical Development Model had a 44% awareness score with only 11% of those respondents who are aware of the model reporting an in-depth understanding. The remainder of this group reported a general (43%) to vague (46%) understanding of the model.

Fifty-five percent the respondents surveyed who used long-term athlete concepts rated the use of the theory as very effective in developing youth athletes. The remaining 45% perceive the use of the models' concepts as somewhat effective. When asked how long term athlete development models could be improved upon in the future, a desire for more individualisation and practical application of the theory within the models is sought (38%), especially in relation to elite or talented junior athletes (13%) (Figure 3.3). Respondents also felt the need for more evidence and further research into the theories and research cited in the existing models (28%). The other main theme that emerged centered on the need for a greater understanding of long term development for everyone involved in junior sport, in particular the coaches, parents, and administrators (22%).

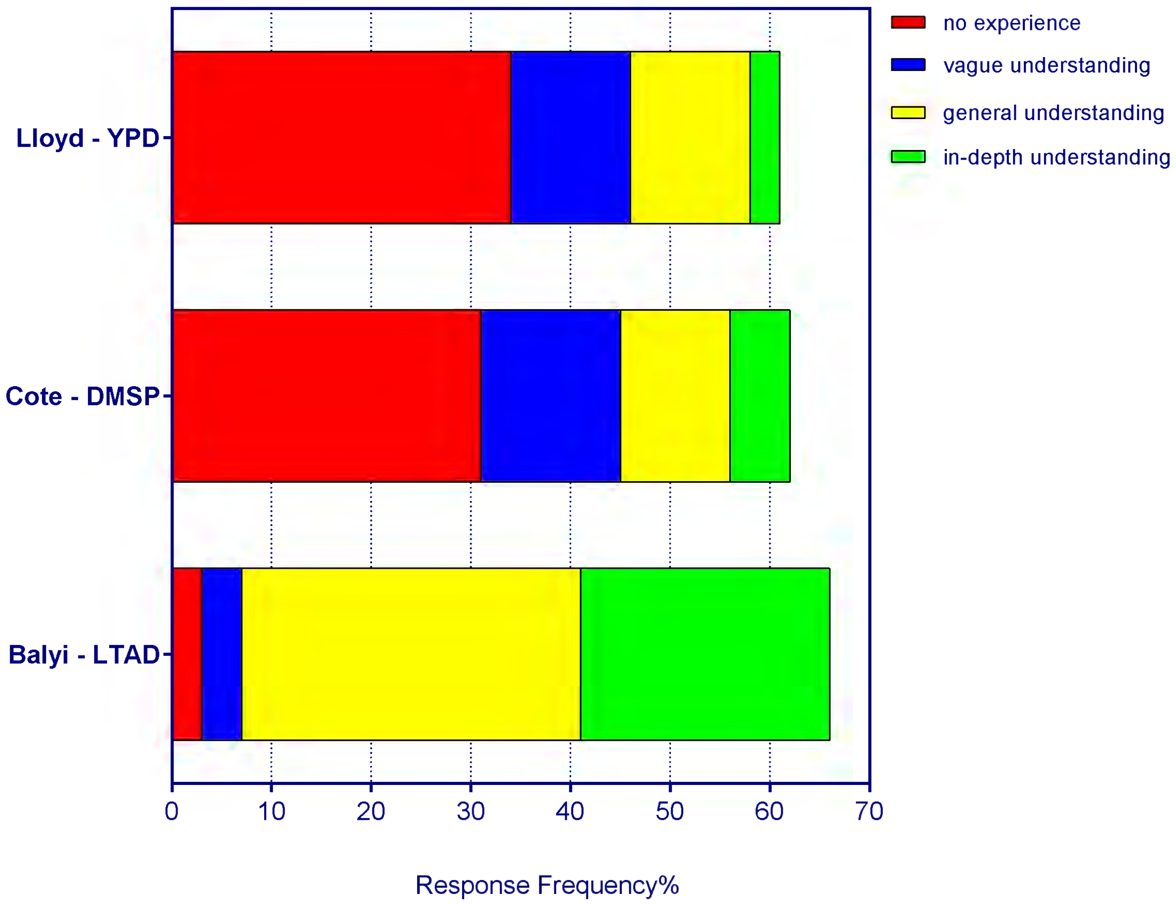

Figure 3.2 - Participants' awareness and understanding of long term athlete models in current literature

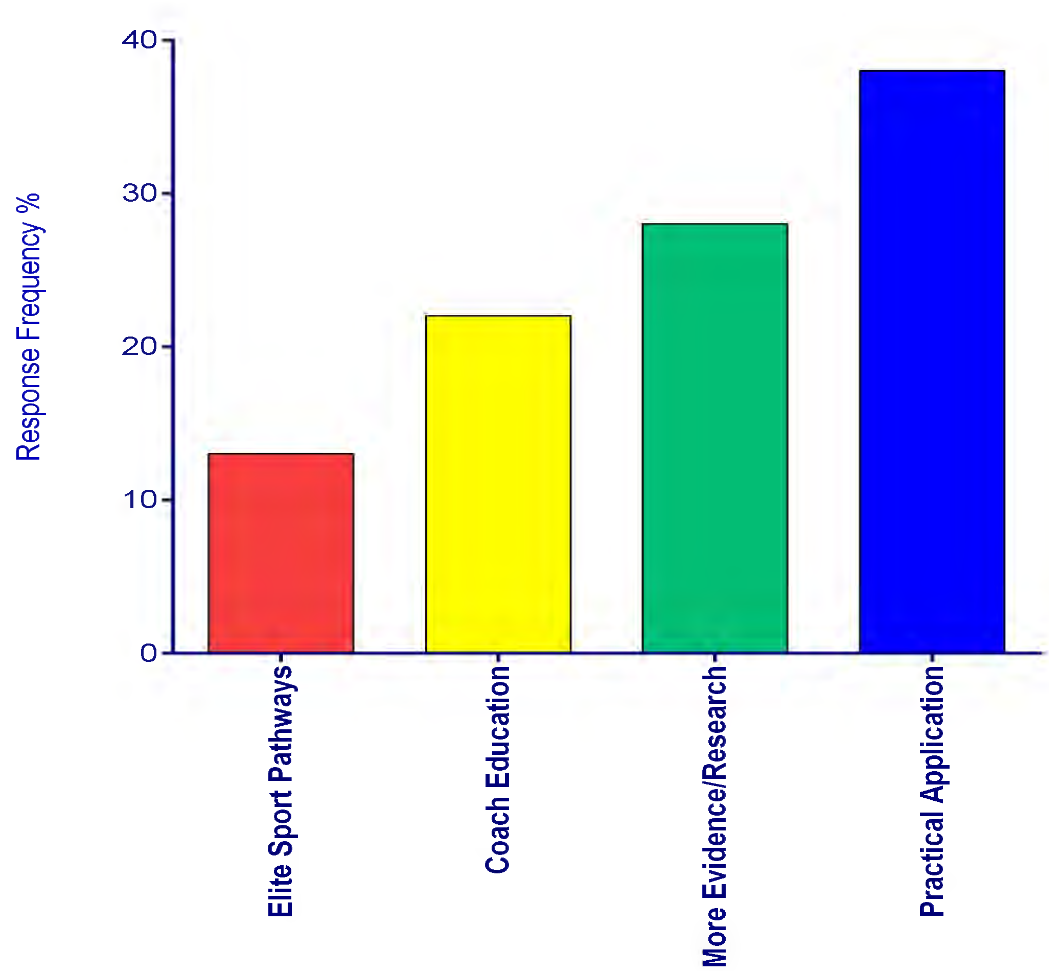

Figure 3.3 - Areas of improvement in long term athlete development models. The bars represent percentage of respondents who stated their desire for more work to be in certain areas.

To assess growth and maturation the most popular measurements utilised in high performance junior athletes were height and weight; each marker is used by 94% of the survey group. Height is the most frequently used marker of growth; measured quarterly (40%) with weight collected weekly (39%) or monthly (26%). Other measures of maturation and growth were not as popular with strength and conditioning coaches in the high performance realm. X-Rays were used yearly or 6-monthly by only 8% of the respondents and ultrasound assessment of bone growth yearly by 5%. Biochemical markers were measured at least once a year by 10 respondents (16%) and secondary sexual characteristics by 8 of the group (13%).

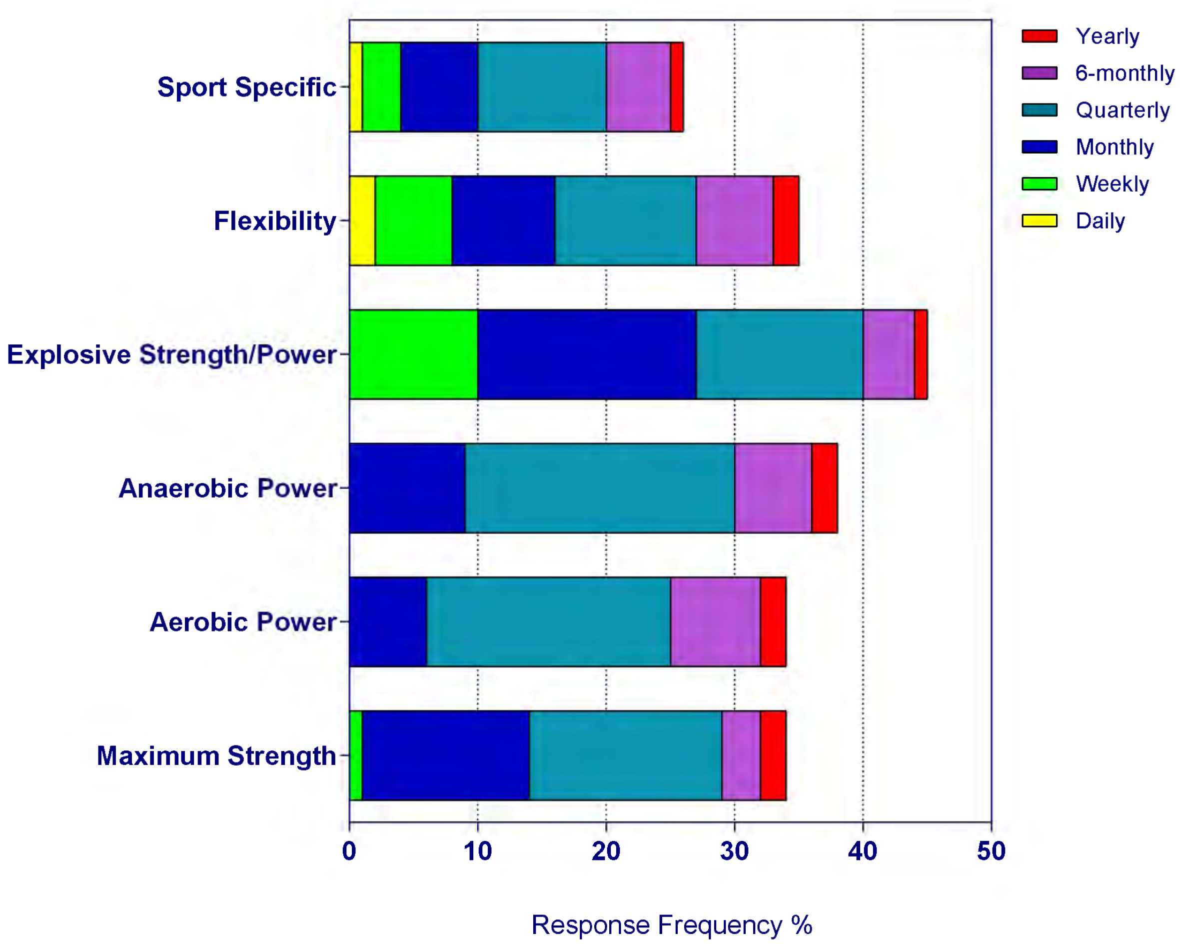

Figure 3.4 - Frequency of performance assessments in junior athletes

All respondents used some form of performance assessment with their athletes. The most popular form of assessment is the assessment of explosive strength or power. Ninety-eight percent of those coaches surveyed measure explosive strength or power on a weekly basis (22%); with the majority of others monitoring changes monthly (38%) or quarterly (29%). Jump performance was the predominant measure of explosive strength, 80% of respondents who stated the use of explosive strength measures assessing performance through countermovement, squat and drop jump using various methodologies and technologies. Sport specific power was observed by 9% and upper body measures of explosive strength such as bench throw and medicine ball throw only used by 7%. Quarterly testing was most popular for other performance measures including maximal strength (42%), aerobic power (48%) and anaerobic power (51%). Sport specific assessment (60%) and flexibility (79%) were also utilised by coaches, primarily on a quarterly basis. The most popular measure of maximal strength was the use of repetition or predicted repetition maximum (79%) for traditional strength exercises of back squat, bench press and bench pull. Yo-yo level 2 (16%) and repeated sprint tests (37%) were the most frequently used measures of anaerobic power. Multi-stage fitness test (24%) and Yo-Yo level 1 (38%) were the most popular aerobic power tests. Only two coaches (4%) found the use of performance assessment useless when dealing with junior athletes, whereas 51% felt they were somewhat useful and 45% very useful. Eighty-four percent of those surveyed performed some form of movement assessment on their athletes. Of this group 84% used their own assessment. Only 7% directly used the Functional Movement Screen (FMS) (44, 45) or an alternative Physical Competency Assessment (PCA) (87) by Giles (9%), although many stated to have evolved their own method from these two key resources (36%). The remaining respondents (48%) have evolved their methods from other undisclosed sources. Movement assessment in junior athletes was rated as very useful by 75% of respondents, with 23% stating they find it somewhat useful. Only one participant reported the method to be useless. Assessment of movement ability was predominantly carried out every 3 months (37%) or every 6 months (37%).

Sixty-four percent of the respondents feel that there are improvements to be made in the current knowledge base in developing youth athletes. The majority of the coaches feel more should be done to clarify research in the area as much is misunderstood and that this information should be delivered to coaches across the pathway (36%). Further areas for research should include more evidence of optimal training windows of adaptation (26%), elite performance pathways considering elite training and competition demands (19%), and the effect of movement development on future athleticism and injury prevention (12%).

3.5 Discussion

The results from this survey highlight the relevance of long term athlete development concepts in high performance sport; however it is clear that more work is required to develop the knowledge of coaches in this field to optimize the concepts' use. Long term athlete development is widely accepted within high performance sport as a concept of how to best train and develop junior athletes appropriately as they prepare for elite sport competition. The model synonymous with long term athlete development is that of Balyi (15, 19, 22-25). His model of LTAD has had tremendous support from national governing bodies and is referenced considerably in youth resistance training guidelines in the Australian Strength and Conditioning Association's position paper (7) and similar position papers of other various professional bodies around the world (139). Criticisms of the evidence to support the model brought forward by Ford (75) are supported by the surveyed group who feel that there are many areas that need to be improved upon in the future. Areas of particular importance for future development that this subject group feel are important include developing more applied guidelines to using the concepts described in the models and educating coaches and parents about the importance of all-round athletic ability for long-term success. The subject group also replied with the need for more research into the mechanisms behind the concepts in order to provide a robust theoretical model in the future. Consideration of the precocious elite performer and how the pathway to high performance success fits into the model of long term athlete development is also felt to be an area that needs exploring to high performance coaches in this survey's subject group. Alternative models have been published and although there is an awareness of Côté (56) and Lloyd's work (120, 121, 124, 159), they are not well understood. Lloyd's Youth Physical Development model is recently published (2012) (121) and as the work disseminates it may get more citations in the future providing an alternative set of guidelines to long term athlete development. The measurement of biological age is strongly recommended across the literature in relation to training junior athletes (109, 139). Biological age can be used as a reference point in the models' guidelines but it is also used to combat the relative age effect seen across many sports (40, 97, 135). The use of height and weight to monitor growth and maturation are the most popular within the surveyed group. The measurement and analysis of this information is simple and cost-effective, hence its' popularity. Professionals may use other techniques such as the use of ultrasound X-Ray for growth and biochemical markers for maturation (109). Since these methods are more expensive and require qualified medical staff to administer and analyse, these resources may not be available to all levels of sport and so alternatives must be found. The use of height and determining the period of peak height velocity (PHV) is used as an indicator of biological age and as a tool to orientate the stages of development referred to in LTAD (19) and in Lloyd's YPD model (121). Predicting PHV from growth data has been proposed by Mirwald et al (137) and is used in previous work investigating the physical performance of junior populations in relation to maturation (120-124). Mirwald's prediction equation of PHV is calculated based upon standing and seated height, date of birth, body mass and is also specific to sex (137). The use of a prospective, predictor of timing PHV such as that of

Mirwald et al (137) and the subsequent use of the guidelines set in place in long term athlete development models would be of advantage to professionals working within high performance junior sport rather than the retrospective analysis of PHV typically utilised when measuring growth in junior athletes.

Junior athletes who are coached by this survey's subject group are assessed for power and explosive strength most frequently, as found in senior athletes (178). Other qualities of athletic performance such as maximum strength, aerobic and anaerobic power are assessed, but not as frequently. A comprehensive 95% of the surveyed group found the use of performance assessment somewhat (51%) to very (45%) useful. The use of performance assessment has previously been used to not only assess current physical levels but utilised to identify future sporting talent. It is proposed that failing to optimise performance characteristics during these windows will result in a failure to achieve a level of physical performance close to ones' genetic potential (19). This is a contentious issue in the literature (75, 123) and in the strength and conditioning profession; this has been identified as an area in need of further research highlighted by the survey respondents. Recent research has begun to address these concerns, with Lloyd and colleagues suggesting that windows of adaptation almost certainly exist in squat jump, countermovement jumps and drop jumps in male youths however different strength qualities may follow a different trend (123, 124). While such research assists our ability to critique the concept of optimal windows of adaptation, training adaptations and numerous other physical performance characteristics still need to be investigated.

Assessment of movement is common within high performance sport across all levels of development. In this survey 84% of all survey respondents use some form of movement assessment. Although FMS (43) and PCA (87) are published and the authors widely accepted as pioneers in the area of movement assessment and development, coaches still favour to adapt their own assessment. The modification tends to be a mixture of previous methods and other assessments, including sport specific assessments. These results would suggest that although the use of FMS and PCA are popular as guidelines to movement assessment, coaches surveyed prefer to develop their own system in accordance with their own coaching environment and philosophy. This lack of uniformity across measurement of movement assessment can make it difficult for coaches and athletes to accurately report and communicate their results with others. This is particularly relevant with national programs or when an athlete moves to a different program or progresses along the pathway. A national or sporting framework from which all coaches based their assessment would ensure accurate records of an athlete's development are reported and ensure parity of assessment. The adaptation to personal preference will illicit more relevant results to individual circumstances, however there needs to be consideration of the reliability and validity of these adaptations if strong recommendations relating to training are to be made from the results.

A limitation of the current survey is the use of potentially leading introductions of each section to frame the questions in the forthcoming section. The authors acknowledge this as a limitation of the survey and highlight this for potential future research into this area of junior athlete development. Future research should introduce each question in neutral language and ensure zero potential bias in any questions asked.

3.6 Conclusion

From this survey it has been shown that within high performance sport there is an understanding of long term athlete development and the various performance and movement assessments that can aid in programming and coaching decisions; however there is a strong desire for further research into these areas with particular emphasis on their practical application in the development of elite sport.

The concept of long term athlete development is popular within sports coaching, however within the field of strength and conditioning coaching it appears that although the models already present in sport are understood there is a lack of practical application in the everyday coaching environment. The models' present at the moment provide effective concepts to base practice off; however in the professional coaches' area there appears to be large areas of interest yet to be explored in research in junior or youth development. Education and deep understanding of the area of long term athlete development appears to be lacking across the coaching pathway from sports coach to strength and conditioning.

Movement assessment in junior and youth development is rated as highly useful, although from the information gathered in this survey coaches tend to be using their own adapted version of a movement assessment. The development of strong foundations in the ability to move well and athletically is critical to future development in sport however the methodology for assessing and correcting movement is largely variable at present as coaches use their own versions of assessment.

3.7 Practical application

It is important that coaches working with junior athletes are aware of the effects of maturation on performance and adaptability to training stimuli. The guidelines presented in coaching texts provide a strong theoretical basis to assist coaches in setting training programs, however scientific validation on such theories are still needed. The consensus from this survey and previous research is that junior athletes must be exposed to wide range of training stimuli, be given biological age appropriate challenges and be afforded the time to train in order to compete successfully in their eventual chosen sport.

At a minimum, using a predictive equation to estimate peak height velocity can provide coaches objective data to assist in individualising training programs for developmental athletes. Assessment of growth should be completed approximately every 3 months or as often as is practical. Observations of performance improvements should be included in all sport programs. In relation to junior programs, performance through a range of sporting demands must be conducted regularly. This will ensure appropriate information is relayed to the coaches in relation to performance and along with the inclusion of a maturity assessment the coach can relate the performance changes to the interaction of maturity on performance.

Barriers to the implementation of any such process have been commented upon by the respondents of this survey. Barriers to implementation surround lack of financing and lack of human resources to practically adhere to the directions above and those from other long term athlete development models. There is an apparent lack of understanding from administrators and a bias towards senior team success at the detriment of resource allocation further down the theoretical pathway of development. It is essential that the importance of sound- long term athlete development principles are communicated to sports administrators to enable coaches to fulfil their duty towards their athletes.

Chapter Four

The following study details the time course and magnitude of changes of power performance in junior elite female athletes. Power in sports performance is often considered a key physical attribute for successful athletes and is a focus of strength and conditioning programs. It is crucial when examining power development in junior athletes to have information relating to the typical values that can be expected and the nature of the response to training.

Time course of improvements in power characteristics in elite development netball players entering a full time training program

I McKeown[1, 2, 3], D. W. Chapman[2, 5], Kristie-Lee Taylor[4] and N. Ball[2]

1. Strength and Conditioning,
   Australian Institute of Sport, Canberra, Australia

2. National Institute of Sport Studies,
   University of Canberra, Canberra, Australia

3. Strength and Conditioning , Australian Capital Territory Academy of Sport, Canberra, Australia

4. Sports Science Department, Australian Capital Territory Academy of Sport, Canberra, Australia

5. Physiology, Australian Institute of Sport,
   Canberra, Australia.

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4.1 Abstract

Fast tracking junior athletes into full time training programs is common practice in high performance sport. The literature describing the changes in performance during this critical period is scarce. ***Purpose***: This study describes the time course of adaptation to strength and power training when entering a full time high performance sport program. ***Methods***: Twelve under-age international netballers (19.9 ± 0.4 y; mean ± SD) performed bodyweight (CMJ) and loaded countermovement jumps (CMJ+) plus drop jumps (DJ) each training week for 18 weeks. ***Results***: Large improvements were observed in CMJ power (24% ± 18%; mean ± 90% confidence limits) and velocity (12% ± 8.1%). CMJ+ power also showed a large improvement (19% ± 12%) but moderate change was observed for velocity (8.4% ± 5.5%). Jump height changes in both CMJ types were unclear (CMJ 9.6% ± 12%; CMJ+ 11% ± 10%). DJ performance improved throughout the study period with reactive strength index showing a moderate positive change (35% ± 24%). Clear substantial changes were observed by week 7 for CMJ power (12 ± 5.9%) and velocity (7.1% ± 3.6%). CMJ+ demonstrated similar changes with substantial velocity improvements by week 7 (7.5% ± 3.3%) and power by week 5 (11% ± 8.7%). ***Conclusion***: Responses to training do not occur linearly in developmental athletes. Variation of these responses may be missed if assessment is limited to jump height. A protocol of frequent assessment of jump performance can aid in program design to ensure improvements are seen past the initial learning phase in training.

4.2 Introduction

Talented athletes who are identified early in their sporting career are often fast-tracked through the sporting development pathway (6). Fast-tracking athletes through the pathway increases the risk of over-competing and under-training these athletes in fundamental functional movements. This can then manifest itself in poor athletic ability, movement dysfunction and injury. Academy or junior development level squads are an introduction to high performance sport athlete pathways. Once an athlete reaches this level they are expected to train and compete at the highest possible level to prepare for future senior success(6). The training load at this level is based on the technical and tactical requirements of the sport that are essential in preparation for later competition. However due to under preparedness at earlier levels or more accurately, over competing in junior sport, it is hypothesised that players are not able to cope with this increase in training load. Players also lack the fundamental movement ability and skills necessary to progress technically and physically(6, 13, 19). The training load is often not only an increase in training volume, but the intensity and complexity of movement is increased without sufficient foundation capacity to improve upon (43).

Academy or junior development level is often the players' first exposure to a fulltime, supervised strength and conditioning program. Given the inexperience of athletes in these situations, the majority of training tends to involve fundamental movement coaching in order to develop a strong foundation of movement ability and core lifting skills as described by the Australian Strength and Conditioning Association and National Strength and Conditioning Association position papers on youth resistance training(67). A program will also aim to elicit strength gains from which to base more complex training modalities. During this stage the improvements in strength training are neural in nature, with a common plateau in improvement rate after six to twelve weeks (67).

Athletes who have been fast-tracked through development pathways often exhibit fundamental movement dysfunction and in most situations a low work capacity tolerance. Coaches must be careful not to overload these athletes too early and ensure that improvements in physical ability are made on top of a strong fundamental movement capacity(68, 141, 155). Strength training gains illustrated in the meta-analysis of resistance training effects in adolescents show a relationship between longer programed interventions and with programs involving more sessions per week (96). Although in female athletes the effect size of this increase is still unclear particularly after the initial increase in performance due to neural adaptation (31). The aim of this study was to describe the time course of adaptation to strength and conditioning practices when junior female athletes begin a full time, supervised program.

4.3 Methods

4.3.1. Subjects

All subjects (n=12) were female netball players selected as part of the residential program of the national sports institute (age 19.9 ±0.4 years; height 1.8 ± 0.6 m; mass 74.1 ± 6.6 kg, and sum of 7 skin folds 76.3 ± 6.0 mm) (mean ± SD). All subjects received a clear verbal explanation of the study, including the risks and benefits of participation. Testing was in accordance with and approved by the Australian Institute of Sport ethics committee, and written informed consent for testing was obtained in the athlete's scholarship holder's agreement. The program focussed on a multi-disciplinary approach to performance with athletes' priorities based around physical, technical and tactical development for elite competition. An example of the physical conditioning workload for a typical week is shown in Table 4.1.

Table 4.1. Distribution of training over a typical training week

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
am	Conditioning	Individual Skills on Court Strength	Individual Skills	Individual Skills on Court Strength	Conditioning (off-Feet)	Strength or Conditioning (off-Feet)	Off
pm	Team Tactical	Team Tactical	Recovery	Team Tactical	Court	Recovery	Off

4.3.2. Design

To examine the time-course of changes in explosive power characteristics in athletes as they enter a full-time, supervised strength and conditioning program, changes in performance were assessed over 18 weeks when subjects were in full-time training. This period included phases of full time training as well as periods of travel and competition where strength and conditioning training was limited. Performance was assessed weekly apart from weeks (3, 7-10, 12-14) where athletes were travelling for competition.

4.3.3. Training Program

During the collection period a typical training week consisted of seven netball sessions on-court, three strength sessions and two off-feet conditioning sessions. Strength training was periodised into five-week blocks with individual exercise selection based upon training competency; however the goal of each block remained the same within the squad. The first five week block aimed to increase general strength and power, and introduce the squad to formal strength and conditioning training. Injury prevention exercises included in the training program were prescribed to improve proprioception as well as include basic hopping and landing tasks and low-level muscle activation drills. Within the program the areas of focus were approximately 40% injury prevention, 50% strength and power, and 10% specific trunk components.

The second five week block goals were to progress strength and power and consolidate technical gains in the primary lifts. Various plyometric and dynamic activities were introduced to the squad, such as loaded jump squats, drop jumps, hurdle jumps, clap push ups, as well as hang cleans, push press. Loads were progressed in the squat, bench press and a variety of other upper body supplementary exercises in rep ranges of three to five for the dynamic movements and four to eight for the strength exercises; sets ranging from three to five. The program ratios were 20% injury prevention, 65% strength and power, 15% trunk control.

During the competition period between weeks 11 and 15 no formal strength sessions were programed due to travel and competition constraints. However, during this period individual injury prevention programs were provided to each player to be completed as often as possible in consultation with the travelling physiotherapist.

The final 4-week block of strength training (weeks 15 to 18) was an identified intensive strength and conditioning block. The purpose of this program was to maintain injury prevention work while increasing maximal strength and power development. Strength sessions included a wide variety of plyometric and dynamic activities, various medicine ball throws, loaded and unloaded jumping, and contrast of heavy squats and box jumps. A maximum of five reps per exercise, and only two to three sets with the focus on speed and quality of movement.

4.3.4. Injuries

During each week the program support team of medical staff would meet to consider and provide consent for each athlete to complete the full training planned for that week. In the event of consent not being granted these athletes performed a modified loading for the week and were excluded from the jump assessment protocol. During the period of investigation there were no injuries that required more than 3 days of reduced training load or time off from full training but some did miss jump assessment. Average attendance at jump monitoring was 73% for the investigation period. Although this may appear to show low compliance, 73% of the total group tested per week is a reflection of the nature of performance sport monitoring where non-participation in the performance task was due to minor injury or training modifications that did not allow for maximal testing, as determined by the medical staff.

4.3.5. Methodology

Following a five minute warm up incorporating dynamic movements and sub-maximal jumping variations subjects performed three maximal effort CMJ at body mass and three repetitions with an additional 15 kg external load (CMJ+). A minimum of five minutes rest was given between jump conditions, which has been shown to minimise the interference of fatigue on subsequent power output (153, 154). During each condition the athlete was instructed to perform the movement with the intent to jump as explosively and as high as possible with a self–selected depth of countermovement. Jumps were performed and measured using a commercially available linear position transducer (GymAware Version 4; Kinetic Performance Technology, Australia). The position transducer was connected to a lightweight (<0.4 kg) wooden pole (CMJ) or 15 kg Olympic Bar (CMJ+) and positioned across the shoulders. The displacement-time data was directly recorded via Bluetooth and after interfacing with commercial software (GymAware Pro). Performance outcomes from the CMJ were peak movement velocity ($m.s^{-1}$) during the concentric phase of the jump, mean concentric power (W) and maximum jump height (m). The typical error (TE) for peak velocity (0.08 m.s^{-1}), mean power (1.7 W.kg), and jump height (0.02m) were calculated prior to testing (102).

Subjects also performed three maximal effort drop jumps (DJ) off a 35 cm box onto a force plate (400 Series Force Plate; Fitness Technology, Adelaide, Australia). They were instructed to jump as high as possible off the force plate with minimal contact time. The force plate was interfaced with computer software (Ballistic Measurement System; Fitness Technology) that allowed direct measurement of force-time characteristics at a sampling rate of 200 Hz. Contact time, and flight time were manually analysed from the force trace output using Ballistic Measurement System Software (version 2010.01). Jump height was derived from the flight time using the following equation: Height (m) = (gravity*(flight time)2/8 where gravity = 9.81 m/s and flight time is in seconds (71). A reactive strength index (RSI) was also calculated by dividing the jump height by the contact time (71). The TE for DJ jump height (0.03m), contact time (0.05s) and RSI (0.18) were calculated prior to testing (102).

4.3.6. Statistical Analysis

The time course of performance changes are presented as the difference from baseline (± 90% confidence limits (CL)). All data was log transformed to reduce non-uniformity of error and the differences were derived via back-transformation as percent changes(101). Standardized differences of the mean were used to assess magnitudes of effects between time points by dividing the differences by the appropriate between-athlete standard deviation. Standardized changes of <0.20, <0.60, <1.2, <2.0 and >2.0 were interpreted as trivial, small, moderate, large, and very large effects, respectively(27, 105). To make inferences about the true (large - sample) value of an effect, the uncertainty in the effects are expressed as ± 90% CL. For the time-course data, a substantial true change in performance (compared to baseline) was accepted when the likelihood of a positive effect was greater than 75%, where the smallest standardized change was assumed to be 0.20(41). Other likelihood values were interpreted qualitatively as follows: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possible; >75%, likely; >95%, very likely; >99% almost certain(105). This procedure was replicated to assess the likelihood of further improvements in performance during the different training phases.

4.4 Results

Large improvements in CMJ power (24% ± 18%; 1.5 ± 1.1) (mean ± 90% confidence limits; standardised change ± 90% confidence limits) (Figure 4.1)and velocity (12% ± 8.1%; 1.1 ± 0.76) in the unloaded jump condition were observed over the 18 week study period. The change in jump height was less clear and may have been trivial to large based on the width of the confidence limits (9.6% ± 12.4%; 0.58 ± 0.74) (Figure 4.2). Similar patterns were observed for CMJ+ with large improvements in power (19% ± 12%; 1.5 ± 0.97), moderate improvements in velocity (8.4% ± 5.5%; 1.0 ± 0.67) and a small improvement in jump height was trivial to moderate (11% ± 10%; 0.59 ± 0.55).

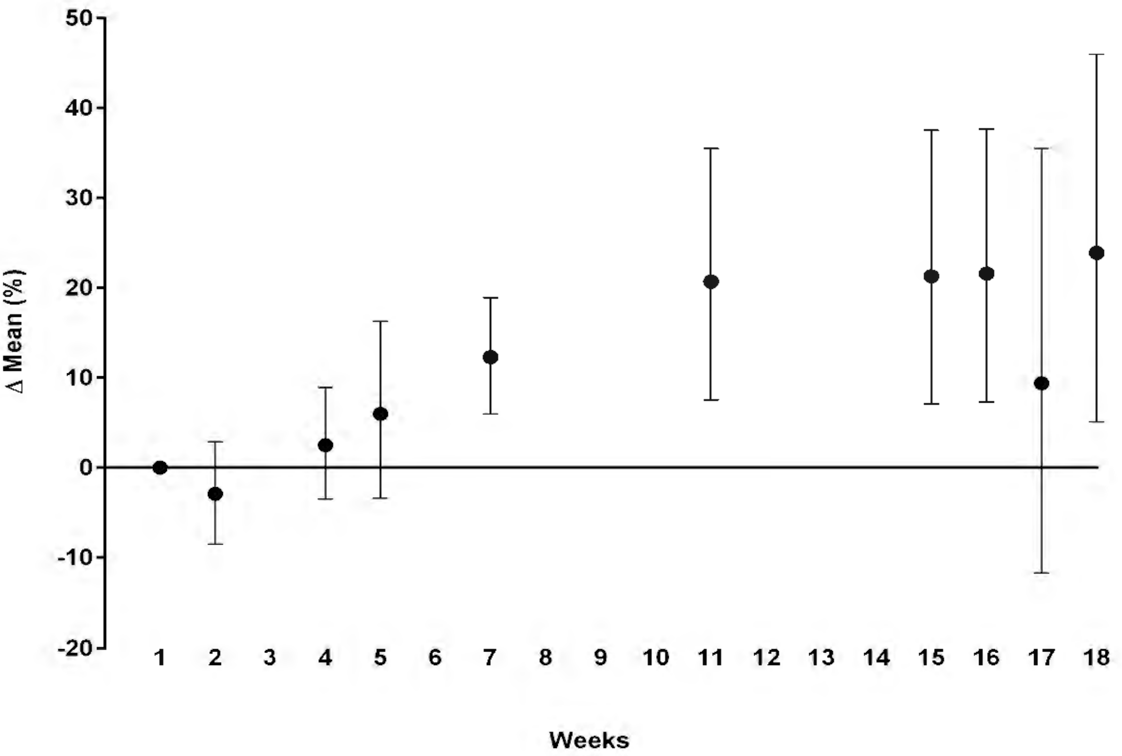

Figure 4.1. Time-course of changes in countermovement jump (CMJ) power performance relative to baseline values over the 18-week study duration. Values are mean ± 90% confidence limits

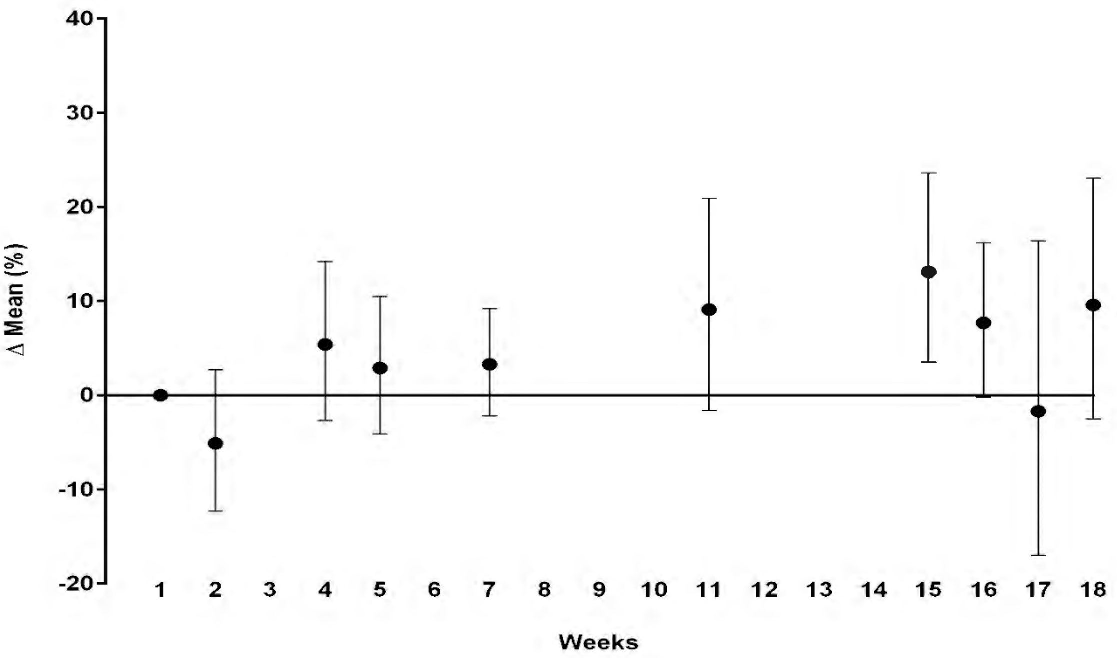

Figure 4.2. Time-course of changes in countermovement jump (CMJ) jump height relative to baseline values over the 18-week study duration. Values are mean ± 90% confidence limits

Analysis of the time course of the changes in unloaded CMJ performance showed a clear substantial improvement by week 7 for CMJ power (12% ± 5.9%; 0.78 ± 0.39) and velocity (7.1% ± 3.6%; 0.66 ± 0.34) whereas jump height did not show clear improvements until week 15 (13% ± 9.3%; 0.78 ± 0.56). There were further small improvements in power (7.2% ± 9.2%; 0.47 ± 0.59), velocity (3.0% ± 3.4%; 0.29 ± 0.32) and jump height (5.5% ± 8.4%; 0.34 ± 0.51) from week 7 to 11 which coincided with second training block focusing on improving power. Changes in performance from week 11 to week 15 were unclear but unlikely to be positive (power = -1.4% ± 10.4%; -0.10 ± 0.67, velocity = -2.5% ± 4.3%; -0.24 ± 0.41, jump height = -2.9% ± 6.5%; -0.19 ± 0.40). Improvements from weeks 15-18 were small for power (4.4% ± 7.5%; 0.29 ±0.49), velocity (2.5% ± 4.5%; 0.24 ± 0.43) and jump height (5.6% ± 6.1%; 0.35 ±0.37) although the confidence limits indicate the effects could have been trivial.

The time course of CMJ+ changes was similar to the unloaded CMJ condition for velocity with clear substantial improvements evident by week 7 (7.5% ± 3.3%; 0.90 ± 0.41). Power was improved by week 5 (11% ± 8.7%; 0.93 ± 0.72) and jump height by week 7 (11% ± 4.7%; 0.59 ± 0.27) which is earlier than the corresponding time points in the unloaded condition. In contrast to the small improvements in unloaded jump performance during weeks

7 to 11, changes in CMJ+ performance were likely trivial during the same period. Trivial changes were also likely from week 11 to 15 for velocity (0.5% ± 1.4%; 0.07 ± 0.18) and jump height (1.3% ± 3.7%; 0.08 ± 0.21), while there was a probable small improvement in power (5.2% ± 6.2%; 0.44 ± 0.51). Trivial (unclear) changes were observed between week 15 and 18 in power (1.2% ± 2.2%; 0.10 ± 0.19), velocity (0.3% ± 2.9%; 0.04 ± 0.35) and jump height (1.4% ± 8.2%; 0.08 ± 0.46).

Drop jump height improved by 10% (0.52 ± 0.40) (standardised change ± 90% confidence limits) from week 1 to 18 (Figure 4.3). The change in contact time between week 1 and 18 was unclear, but a moderate improvement in RSI was very likely (35% ± 24%; 0.97 ± 0.69). Substantial improvements in DJ height were observed by week 5 (8.1% ± 8.5%; 0.42 ± 0.44), whereas substantial reductions in contact time were not evident until week 7 (15% ± 22%; 0.69 ± 0.86). Moderate negative changes from week 16 to 18 were very likely for DJ height (10% ± 8.3%; ES 0.58 ± 0.43) and likely for RSI (12% ± 19%; ES 0.42 ± 0.55).

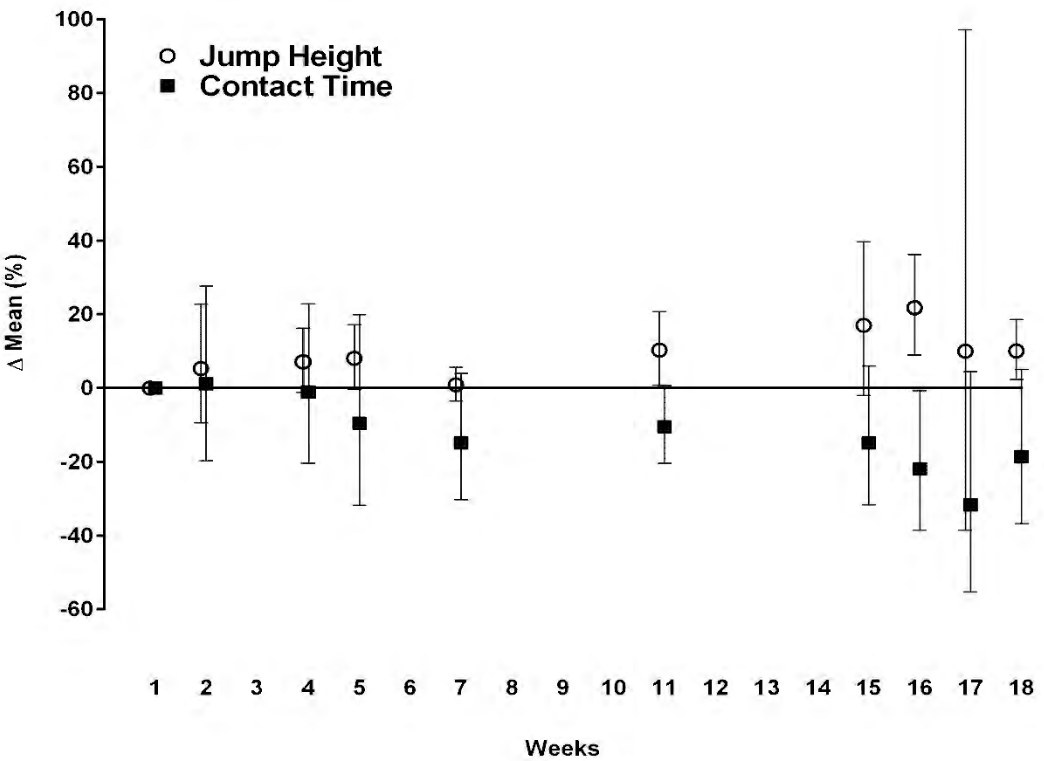

Figure 4.3. Time-course of changes in drop jump (DJ) performance relative to baseline values over the 18-week study duration. Values are mean ± 90% confidence limits.

4.5 Discussion

The results from this study provide an insight into the time-course of jump performance improvement in elite developmental athletes who are entering a full time sports training program for the first time. Clear improvements in jump performance were observed over the 18 week training block, most of the improvement occurred within the first 7 weeks, with minimal improvements throughout the remainder of the observed period. There were no further improvements during the competition period with unlikely small improvements in unloaded CMJ performance and only trivial changes in CMJ+ performance. The final period of the training program resulted in small improvements in CMJ, CMJ+ and DJ performance however these changes are unclear and possibly trivial.

The moderate to large initial improvements in power and velocity observed in this study are similar to the magnitude of changes seen in similar training studies of untrained subjects to strength or power training(51, 52, 60). Unfortunately most previous studies investigating changes in junior athletes have reported jump height in isolation without investigating changes in power or velocity as included in the current study. The direct calculation of power is necessary during performance assessment as enhancement of power is considered a crucial element of athletic performance rather than only jump height(4, 167). Vertical jump height is however thought to provide a valuable marker of muscular power and therefore is commonly used as an indicator of broader athletic performance (33). After entering a supervised strength training program for the first time, moderate improvements in jump height (10%) were observed in young rugby league players(60). Significant improvements in jump height have also been reported in junior female basketball players following seven weeks (8%)(148) and six weeks (8%) (155) exposure to a neuromuscular training intervention using comparable methods of strength training to the present study. However following six weeks of training the effect size was trivial (0.09)(155). Similarly the changes in jump height over the time course of the present study were unclear, suggesting other variables should be investigated in order to best understand the complex interaction of performance variables in response to training. The moderate to large improvements observed in power and velocity in the present study are larger effects than previously reported. Small to moderate changes for performance variables of jump height (ES 0.23), relative power (ES 0.79) and peak velocity (0.67) were reported utilising full time athletes in an intensive training program for strength and power development over 12 weeks(168). Our results indicate the potential for larger changes seen in performance between development athletes, who are still relative novices in terms of strength and power development, and a well-trained group of athletes(51, 52, 179).

Injury prevention programs have reported significant improvements in drop jump technique in female athletes knee valgus angles after four week training intervention but have not reported DJ height changes(98). The modes of training used in this type of study aim to improve injury prevention indices for non-contact injuries, particularly anterior cruciate ligament rupture. Injury prevention training alone will not provide adequate stimulus to enhance jump performance while decreasing ground reaction force on landing and other injury prevention markers(181). Training studies involving junior female athletes that focus on performance found trivial improvements in vertical jump height and small improvements in drop landing technique after six weeks in untrained basketball players(155). No strength gains in the exercises used were reported. The strength training techniques utilised in the aforementioned study however involved the use of weights machines and other techniques not necessarily considered appropriate for a professional strength and conditioning in high performance to utilise. Although injury prevention is a critical element of any strength and conditioning program, in order to improve performance on-court, performance enhancement goals must also be reached. By enhancing athletic performance in a training program it has been suggested that the additional benefits of such a program will also increase compliance to training program and inadvertently this can increase in the opportunity for injury prevention work to be continued(155).

The results from the current study show that competition could potentially have a negative effect on physical development; however the net gains over the entire training period still confirm a substantial improvement in jump performance. The confounding effects of competition and training have been previously reported by Sheppard and colleagues(167) in senior elite volleyball players with similar improvements in jump performance as reported in the current study. During this time, focus was on competition and tactics opposed to physical conditioning thus the frequency of performing any physical training including strength training or other neuromuscular training would have been reduced. Competition is however a key element of any high performance sport’s program, and is vital that high-level game exposure is sought, particularly at this late stage in a players’ development(92). The scope of the current study does not consider the inclusion of competition may have had a positive effect on all other elements of on-court performance, even if physical performance was temporarily affected. The net gain in sports performance is an important element for strength and conditioning professionals and sports coaches to consider when planning and administering any program.

This study has described the time course of adaptation to jumping performance in a full time strength and conditioning program. Improvements made over the first period do not continue to increase linearly or at the same magnitude across the jump variables after the initial familiarisation period. Time must be taken to monitor the variables accurately and to prescribe adequate training stimulus to improve jump performance and subsequent athletic performance after the initial neural adaptation to training in novice performers. Improving the players' long term athletic development by eliminating as many decrements as possible should be an aim of the strength and conditioning program. Over time there will however be variations in performance measures, athletes will not continually improve linearly. The role of the strength and conditioning coach should be understand these interactions and plan accordingly to maintain a positive environment for adaptation, performance and technical improvement.

4.6 Practical applications

During the first period of training exposure to a full time training program junior athletes can show improvement across a range of jump performance variables. Jump performance will not improve linearly or at the same rate for all jump types. Frequent monitoring of performance variables across different jump types will inform the coach when a plateau has been reached in performance improvement. The coach can then vary the program to expose the athlete to a new stimulus to ensure continual improvement in performance. Jump height is not the most sensitive to change therefore other variables that can be easily measured must be considered in a high frequency monitoring program.

To improve the effectiveness of an end-of-development/sub-elite program such as that utilised in this study; a foundation program should be introduced ensuring appropriate prior training background has been reached before entering the high performance sport program. This will encourage performance improvement in physical qualities rather than basic neuromuscular familiarisation and neural adaptation. The initial neural adaptation should ideally not be the primary source of adaptation in this level of athlete.

Chapter Five

The nature and magnitude of strength and power development in junior athletes is largely unreported in the literature. An improved understanding of how athletes respond to strength and power training, especially during their first exposure to a high performance training program, may be useful in interpreting the magnitude of performance improvements expected in these sub-elite athletes.

Time course of power response to introduction into a performance training environment in junior pre-elite athletes

Ian McKeown[1, 2, 3]

David B Pyne[4]

Nick Ball[2]

1. Strength and Conditioning,
Australian Institute of Sport, Canberra, Australia

2. National Institute of Sport Studies,
University of Canberra, Canberra, Australia

3. Strength and Conditioning Department, Australian Capital Territory Academy of Sport, Canberra, Australia

4. Department of Physiology, Australian Institute of Sport, Canberra, Australia

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5.1 Abstract

The time-course and magnitude of strength and power development in junior athletes is largely unreported in the literature. The purpose of this study was to measure fortnightly changes in power performance through countermovement jumps (CMJ), loaded (CMJ), concentric-only squat jumps (SJ), and drop jumps (DJ) over the initial phase of a strength and power training program. Subjects included 12 male volleyball players (18.0 ± 0.8 y, 197 ± 5 cm, 85 ± 9 kg; mean ± SD) and 18 female basketball players (18.0 ± 1.1 y, 182 ± 8 cm, 73 ± 8 kg). At the end of the testing period the volleyball players had improved CMJ and DJ performance by small-moderate amounts (mean ±90% confidence limit; 9.5 ±6.8%; and 10.3 ±10.2% respectively), while the basketball players only showed clear improvements in DJ performance (13.1 ±9.6%). The time-course results, however, suggest that typical post-pre analysis of training programs may be misleading, and that more frequent assessment throughout the training period may provide valuable insight into the timing of neuromuscular adaptions to strength and power training in athletes. Frequent assessment of these qualities throughout the training program is therefore recommended since practically important changes related to the time-course of adaption may be otherwise missed.

5.2 Introduction

Training methodologies for strength and power development in elite athletes have been extensively investigated in applied sports performance research (46, 61). Less work exists regarding the training methods and outcomes for junior athletes as they enter high performance training environments. Generally, the basis of training programs for junior athletes is formed upon popular models of long-term athlete development (6, 56, 163) and youth resistance training guidelines (7, 67). However these models are largely theoretical and some criticism has arisen recently over the practicality of the recommended training methods and the lack of scientific basis of some of these training principles (6, 75). One of the first steps in improving the evidence-base for training methodologies for junior athletes is furthering our understanding of their typical responses to training. In particular, there is a lack of information pertaining to the adaptions to training in the later stages of adolescence, which generally equates to the 'specialisation' or 'training to compete stage' of the athlete's individual development.

The ability to express power is considered one of the main determinants between successful elite athletes and sub-elite athletes (168, 169). Vertical jumps are popularly used to assess power characteristics in athletes (152, 167, 172). Strength and power profiling, using a variety of vertical jump protocols that rely on different neuromuscular qualities, enables a range of strength and power qualities to be assessed in one testing protocol. The comparison of vertical jump results from different conditions, such as concentric-only squat jumps, countermovement jumps, and drop (depth) jumps, can provide the strength and conditioning coach with insight into the training needs of an individual, informing coaches of areas of strengths and weaknesses that need focused attention (54, 172, 185). Conversely, relying solely on the assessment of one quality can lead to unreliable and invalid assumptions about the training status and adaptation to a program (51, 52).

Reference values of strength and power characteristics have been published for senior (4, 82, 83, 175), and junior athletes from a range of sports (36, 83, 186). Reference values published; although useful do appear to use different methodologies and calculations for measuring power (48). The disparity in measurement systems has led to confusion over comparing values of different systems (187). These reference values are nevertheless important in assisting strength and conditioning coaches. Knowledge of reference values in both populations can assist strength and conditioning coaches and other practitioners in understanding the nature of physical qualities in athletes from different sports and populations, and in diagnosing the strengths and weaknesses of particular athletes by comparing their results with published reference values. However, knowledge of reference values representing the typical magnitude and time-course of adaptions to strength and power training is also very important for training program design and the evaluation of an athlete's response to training. Recent evidence suggests that elite athletes submersed in a high-performance training environment will have marked improvements in strength and power during the first 12 months, and minimal improvements thereafter (i.e. 2–4 years) (134). An improved understanding of how athletes respond to strength and power training, especially during the initial stages (four to five months) of a high performance training program, should be useful in prescribing and adjusting strength and conditioning programs. Anecdotal reports indicate the improvement in strength and power is neither linear nor continuous in nature, and details on the degree of variability would be useful in inform training prescription. The aim of this study was to describe the time-course of changes in a range of strength and power characteristics in sub-elite junior athletes' throughout their initial exposure to a full-time strength and conditioning program.

5.3 Methods

5.3.1. Experimental Approach to the Problem

To assess the time-course of power adaptation in the first phase of a full-time training program, changes in strength and power characteristics were assessed fortnightly in two athlete cohorts. The testing period lasted 16 weeks in the volleyball group and 20 weeks for the basketball group. Performance in countermovement jumps, concentric-only squat jumps and drop jumps was assessed during regular strength and conditioning program whenever subjects were on residence at the national sports institute. Testing was performed each week, with half the subject group participating on alternate weeks. The strength training program during the study consisted of mainly the development of fundamental lifting skills, including Olympic lifts and their derivatives. Programming was structured in four-week cycles of typical general preparation set and rep ranges. Sets ranged from 2-5 and rep ranged from 3-6 for strength and power and higher for either supplementary or corrective exercises. No tapering was present during the study period. Basic plyometric exercises were also included in the training program for injury prevention and performance enhancement purposes. Training programs were prescribed by the team strength and conditioning coach – the study was observational in nature with high ecological validity but lower experimental control (157).

5.3.2. *Subjects*

Thirty subjects who were selected in the residential program of the national sports institute in either volleyball (n = 12, male) (18.0 ± 0.8 y, 197 ± 5 cm, 85 ± 9 kg; mean ± SD) or basketball (n = 18, female) (18.0 ± 1.1 y, 182 ± 8 cm, 73 ± 8 kg) were recruited for this observational study. Biological maturity of each athlete was assessed via the non-invasive technique proposed by Mirwald and colleagues (2002) using measures of standing height, sitting height, age, and body mass to calculate maturity offset value (years from peak height velocity) (137). Based on these measurements, both groups were identified as being post-PHV. Volleyball was (mean ± SD) 4.6 ± 0.6 years past their PHV and basketball were 2.2 ± 1.0 years past their PHV. During their scholarship the athletes participated in a minimum of three sport training sessions and three strength sessions per week. Training age for all subjects in the study was between 0 and 2 years of formal strength and conditioning coaching. All subjects received a clear verbal explanation of the study, including the risks and benefits of participation. Testing was in accordance with and approved by institutional ethics, and written informed consent for testing was obtained in the athlete's scholarship holder's agreement.

5.3.3. *Procedures*

Following a five minute warm up incorporating dynamic movements and sub-maximal jumping variations, subjects performed six maximal effort countermovement jumps (CMJ) with no external load, six repetitions with 15 kg (basketball) or 20 kg (volleyball) external load (CMJ+), six concentric-only squat jumps (SJ), and six drop jumps. Approximately five minutes rest was given between jump conditions. For each type of jump the athlete was instructed to perform the movement with the intent to jump as explosively and as high as possible with a self –selected depth of countermovement (where applicable).

Countermovement- and squat jump performance was assessed using a commercially available linear position transducer (GymAware Version 4; Kinetic Performance Technology, Australia). For each jump the position transducer was connected to a lightweight (<0.4 kg) wooden pole (CMJ) or 15/20 kg Olympic Bar (CMJ+) and positioned across the shoulders. The displacement-time data was directly recorded via Bluetooth and after interfacing with commercial software (GymAware Pro). For squat jumps, subjects held the wooden pole across their shoulders and began the trial with knee flexion at approximately 110° and an upright torso. They were instructed to maintain that position for approximately 3 seconds then cued to jump with no countermovement. All trials were visually analysed by the investigators for any small amplitude countermovement as recommended by Sheppard and Doyle (171). Performance outcomes from CMJ, CMJ+ and SJ were mean concentric power ($W.kg^{-1}$) and maximum jump height (m). The typical error (TE) for CMJ, CMJ+ and SJ were calculated prior to testing, for mean concentric power the values were 2.6, 5.2 and 2.6 $W.kg^{-1}$ and 0.01m in all jump conditions for jump height.

Drop jumps (DJ) were performed off a 30cm box onto a timing mat (Speed Mat, Swift Performance Equipment; Australia). Subjects were instructed to jump as fast and high off the mat on landing; with values for contact time (s) and jump height (m) recorded. The reactive strength index (RSI) (TE; 0.13) was used to describe the interaction of contact time and jump height (RSI = contact time/jump height) (71).

5.3.4. Statistical Analyses

The time-course of performance changes are presented as the difference from baseline (± 90% confidence limits (CL)). Data were log-transformed prior to analysis to reduce non-uniformity of error and the differences were derived via back-transformation as percent changes (101). Standardized differences of the mean were used to assess magnitudes of effects between time points by dividing the differences by the appropriate between-athlete standard deviation. Standardized changes of <0.20, <0.60, <1.2, <2.0 and >2.0 were interpreted as trivial, small, moderate, large, and very large effects, respectively (27, 105). To make inferences about the true (large - sample) value of an effect, the uncertainty in the effects are expressed as ± 90% CL. For the time-course data, a substantial true change in performance (compared to baseline) was accepted when the likelihood of a positive effect was greater than 75%, where the smallest standardized change was assumed to be 0.20 (41).

5.4 Results

The post-pre analysis for the volleyball group resulted in small and moderate improvements in CMJ height and power respectively (Table 5.1). Changes in CMJ+ height and power were trivial. Changes in SJ height and power were trivial and DJ RSI improved by a small magnitude.

The standardised changes in jump performance for the basketball group were less clear (Table 5.2). CMJ+ power and SJ power improved by the largest magnitude, with all other CMJ and SJ outcomes unclear. The improvement in DJ RSI was small. For both groups, improvements in power generally were greater than the improvements in jump height (except for trivial changes in both for volleyball SJ).

Table 5.1 – Changes in countermovement jump (CMJ), loaded countermovement jump (+20kg) (CMJ+), squat jump (SJ) and reactive strength index (RSI) in junior volleyball players (male) following 16 weeks of strength and power training.

	Pre (mean ±SD)	Post (mean ±SD)	% Change (90% CL)	Effect Size (90% CL)
CMJ Power ($w.kg^{-1}$)	41.9 ±4.8	46.5 ±5.1	9.5 (2.5 – 17)	0.72 (0.2 – 1.2)
CMJ Jump height (cm)	46.9 ±5.0	49.2 ±4.2	3.8 (0.1 - 7.6)	0.31 (0.0 – 0.6)
CMJ+ Power ($w.kg^{-1}$)	35.5 ±5.1	37.6 ±4.8	3.2 (-3.0 – 9.8)	0.19 (-0.2 – 0.6)
CMJ+ Jump height (cm)	40.0 ±5.2	41.8 ±2.6	1.6 (-2.3 – 5.7)	0.10 (-0.1 – 0.4)
SJ Power ($w.kg^{-1}$)	33.5 ±3.0	34.3 ±3.5	1.2 (-4.2 – 6.8)	0.12 (-0.5 – 0.7)
SJ Jump height (cm)	43.4 ±4.5	44.2 ±3.5	0.9 (-1.5 – 3.5)	0.08 (-0.1 – 0.3)
RSI ($m.s^{-1}$)	1.64 ±0.4	1.78 ±0.4	10 (0.2 – 22)	0.4 (0.0 – 0.8)

Table 5.2 – Changes in countermovement jump (CMJ), loaded countermovement jump (+20kg) (CMJ+), squat jump (SJ) and reactive strength index (RSI) in junior basketball players (female) following 20 weeks of strength and power training.

	Pre (mean ±SD)	Post (mean ±SD)	% Change (90% CL)	Effect Size (90% CL)
CMJ Power ($w.kg^{1}$)	33.4 ±4.6	36.7 ±4.1	6.2 (-4.2 – 18)	0.4 (-0.3 – 1.1)
CMJ Jump height (cm)	34.5 ±2.7	35.7 ±4.4	-0.2 (-9.0 – 9.5)	-0.03 (-1.1 – 1.1)
CMJ+ Power ($w.kg^{-1}$)	29.4 ±3.0	31.8 ±2.8	7.7 (0.7 – 15)	0.7 (0.1 – 1.3)
CMJ+ Jump height (cm)	30.3 ±2.4	30.9 ±3.1	2.4 (-3.1 – 8.3)	0.3 (-0.4 – 1.0)
SJ Power ($w.kg^{-1}$)	28.3 ±3.7	30.6 ±4.6	11 (-3.5 – 27)	0.7 (-0.2 – 1.6)
SJ Jump height (cm)	33.5 ±2.8	33.7 ±4.3	2.1 (-6.1 – 11)	0.2 (-0.7 – 1.2)
DJ RSI ($m.s^{-1}$)	1.34 ±0.4	1.44±0.3	13 (3.2 – 24)	0.4 (0.1 – 0.8)

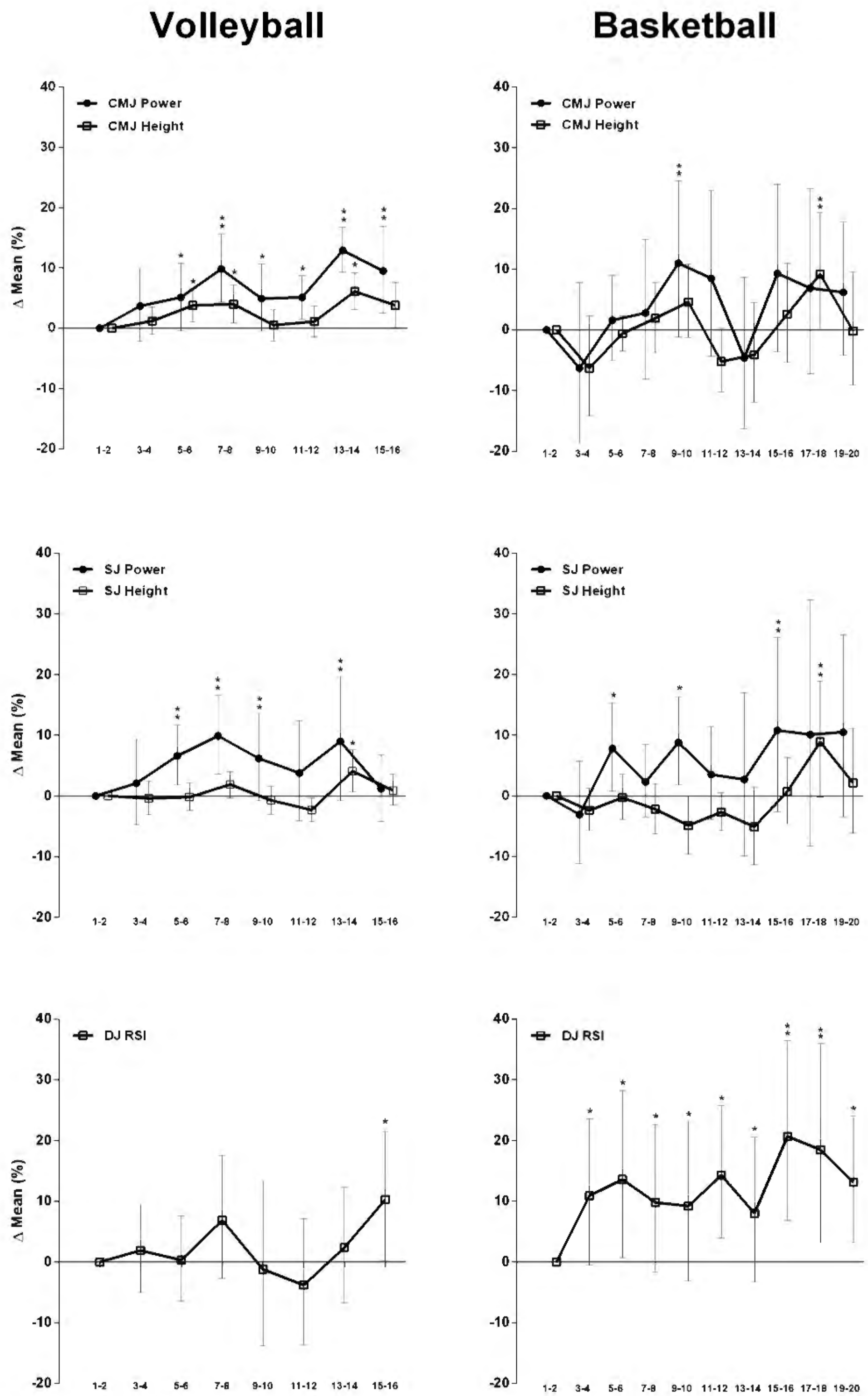

Figure 5.1 – The time-course of changes in countermovement jump (CMJ), squat jump (SJ), and the reactive strength index calculated from a drop jump (DJ RSI), in junior volleyball and basketball players during their first exposure to a full-time training program. Asterisks are indicate clear, substantial improvements in performance compared to baseline performance, where * denotes a small standardised effect and ** denotes a moderate effect. Data points are mean ± 90% confidence limits.

The time-course of changes from test to test for both groups is illustrated in Figure 5.1. Based on a likelihood of a positive adaption greater than 75%, substantial performance improvements in CMJ and SJ power were first observed by Week 9-10 in volleyballers. This performance enhancement was mostly maintained for CMJ; however performance decreased substantially in the final SJ test, which is reflected in the trivial effect for overall performance change in this jump type (Table 1). A substantial performance improvement in DJ was not observed until the final assessment.

In the basketball group, the first clear and substantial improvement in CMJ power was observed in Week 9-10, but this effect was unclear for the remainder of the testing period. Similarly a substantial improvement in CMJ height was observed in Week 9-10, with a further clear improvement evident at the Week 17-18 test. This improvement was not maintained in the final test.

Small improvements in SJ power were clear for the basketball players during Week 5-6 and 9-10 and continued to improve with moderate enhancements observed from 15-16 through to the final test. Improved SJ height was only observed in Week 17-18, but this improvement was not maintained in Week 19-20. Improvements in RSI occurred early and were clear from Week 3-4 onwards.

5.5 Discussion

The aim of this study was to describe the magnitude and time-course of changes in power characteristics when junior athletes were introduced a full-time residential training program. At the end of the testing period the volleyball players had improved CMJ and DJ performance by small-moderate amounts, while the basketball players showed clear improvements in RSI only. The time-course results, however, suggest that typical post-pre analysis of training programs may be misleading, and that more frequent assessment throughout the training period may provide valuable insight into the timing of neuromuscular adaptions to strength and power training in athletes new to full time training programs.

The moderate increase in CMJ power (13%) observed in the junior volleyball players after 13-14 weeks of training is similar to the 15% improvement previously reported for CMJ peak power in volleyball players after transitioning into the senior national team (172) and the 13% improvement in elite Australian Rules Football (ARF) players over multiple seasons (131).

Interestingly, the performance improvements the junior players in this study occurred as early as 7-8 weeks into the program, compared to similar performance improvements following two and three years of strength and power training in the senior volleyball players and ARF players respectively. These findings support previous research suggesting that as an athlete's training age and experience increases, the rate of strength and power adaptation diminishes and may begin to plateau (3, 9, 72, 108).

The overall changes in SJ performance in the volleyball group were trivial, which does not support early changes with the introduction of systematic strength and power training as above. However, while the changes were trivial based on the post-pre analysis, the time-course analysis of SJ power shows moderate changes occurring as early as 5-6 weeks into the program, with those improvements lasting until the second to last performance test in Week 13-14. The discrepancy between the outcomes throughout the training period and final testing occasion highlights the advantage of frequent monitoring. As seen in this analysis, the timing of assessments can significantly affect the reported outcomes, which may be misleading. This is exemplified by the interpretation of the changes in SJ power over 16 weeks as trivial, rather than understanding that moderate improvements were evident at multiple other time points throughout the training period. To avoid misinterpretation of changes, and to better understand the time-profile of improvements, it is recommended that changes in strength and power be monitored frequently across different phases of the athletes development, and at least multiple times throughout phases of training.

The small improvement in CMJ height (4%) observed in the volleyball group in the current study is lower than the 11% improvement that reported by Sheppard et al. (172) over the two-year training period. In this study, improvements in jump height were consistently smaller than the improvements in power in both groups and jump types (Figure 1). An uncoupling between improvements in jump height and power have been noted previously in elite ARF (131). However this finding has not been replicated in other long-term monitoring studies where the magnitude of changes in height and power are reportedly similar (172). We suggest that the differing time-course of power and jump height may be due to an earlier adaptation in power producing capabilities. It may be that more time is needed to transfer the newly acquired power into a coordinated movement that results in greater jump height, although this does not explain the uncoupling of jump height and power changes observed in elite athletes in longitudinal studies whereby we would expect that there is plentiful time for these athletes to transfer the newly acquired power. More work is required to understand these relationships in both pre-elite and elite populations.

In the female basketball group, clear improvements in SJ power were evident after 5-6 weeks of training. However, along with other moderate improvements throughout the remainder of the training period, the final improvement of 11 ±15% (±90% CL) was unclear. The improvement after 5-6 weeks supports the finding of early adaptions in power with the introduction of specific strength and power training. There was a clear 11% improvement in CMJ power in Week 9-10 but again the results for the remaining assessments were unclear for this variable. The clear improvements that were observed in this group are greater than previously reported in female gymnasts of the same age range (78) who did not improve significantly during the first year of strength training, but less than the 18% improvement in CMJ peak power in female volleyball players following a 16 week pre-season training phase (164). Significant improvements in CMJ (46%) and SJ (43%) peak power were observed following the third year of training in gymnasts, suggesting that the systematic application of resistance training and power training in female athletes in this age group can result in large improvements beyond the initial adaptions.

Strength and power profiling often includes drop jumps for the assessment of intermediate or fast stretch-shortening cycle (SSC) activity, whereby an improvement in RSI can be used to indicate an enhanced SSC function. Improvements in RSI (13%) were evident late in the training period for volleyball players. There was also a clear improvement in RSI in the basketball group, which occurred very early (Week 3-4). It is likely however that this initial improvement was due to a learning effect, since there were only trivial changes in RSI when the second time point was used as the baseline measure (3 ± 7%). The trivial enhancements in RSI in the female athletes are consistent with insignificant improvements in RSI in very young athletes (12-15 years old) (125).

The information from the studies discussed here alongside the findings from the present study provide valuable information for performance standards and the expected rate of improvement in junior pre-elite athletes as they are exposed to specific strength and power training programs. The present study adds to this body of knowledge as it not only provides values for comparison but describes the time course and the magnitudes of the adaptation to training that can take place in this sporting population. The use of different sexes and the different training modalities that were uncontrolled for in this study are acknowledged as limitations in the study design. However, the usefulness of the information reported and the discussion emanating from such is still believed to provide further insight into the adaptation of training in junior athletes.

5.6 Practical applications

Monitoring changes in strength and power characteristics of athletes over time is an important consideration for strength and conditioning professionals and sports scientists working with elite and pre-elite athletes. Pre-elite athletes adapt quickly to training in the initial stages of a full-time training, with improvements in CMJ and SJ power preceding improvements in jump height. Frequent assessment of these qualities throughout the training program is recommended since practically important changes related to the time-course of adaption may be otherwise missed.

Chapter Six

The ability to move well can have an impact on sports performance. Coaches will tend to look at athletes ability to move and through training attempt to improve on this quality. The assessment of foundation movements in sports performance is popular in contemporary strength and conditioning practices. However, from Chapter 3 high performance sports professionals do not utilise the protocols in the literature to date. The following study introduces the Athletic Ability Assessment (AAA) as a movement assessment tool designed to meet the needs of athletic populations.

Athletic ability assessment: a movement assessment protocol for developing athletes

I McKeown[1, 2, 3], Kristie-Lee Taylor[4] and N. Ball[2]

1. Strength and Conditioning,
Australian Institute of Sport, Canberra, Australia

2. National Institute of Sport Studies,
University of Canberra, Canberra, Australia

3. Strength and Conditioning , Australian Capital Territory Academy of Sport, Canberra, Australia

4. Sports Science Department, Australian Capital Territory Academy of Sport, Canberra, Australia

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6.1 Abstract

Movement ability is an often overlooked component of physical performance research and needs to be considered alongside the appraisal of physical fitness and performance characteristics. To achieve this, a standardised assessment tool is required. ***Purpose***: In this paper we introduce a new method for assessing movement ability and present results for intra- and inter-rater reliability. ***Methods:*** Female soccer players (n=17) were assessed using the Athletic Ability Assessment (AAA) by the primary researcher in real-time and via video on two separate occasions to estimate intra-tester reliability. Inter-tester reliability was estimated using the difference between 5 other testers' video-based scores. ***Results:*** The intra-tester typical error (TE) for the composite AAA was 2.9 points (90% confidence limits; 2.3 – 4.2 points) (2.5%; 2.0 – 3.6%) with an intraclass correlation coefficient (ICC) of 0.97 (0.92 – 0.99). Inter-tester TE for the composite AAA scores was 2.8 points (2.5 – 3.3 points) (2.4%; 2.1 – 2.8%) with an ICC 0.96 (0.94 – 0.98) Individual test scores for the intra- and inter-tester show a similar range TE of between 0.4 – 1.1 points. ***Conclusion:*** Results of the reliability analysis suggest high levels of agreement between scorers in differing conditions and provide reference values for changes using the AAA. The AAA is a viable alternative movement assessment protocol that addresses specifically sporting populations. The AAA can be utilised in performance research to establish relationships between sports performance and AAA scores, along with association with injury in the future.

6.2 Introduction

Developing athletes require a strong foundation in a diverse range of athletic qualities in order to progressively train and compete successfully. The development of these foundation movements early in the athletes' development pathway is one of the key recommendations of long term athlete development(6, 7). Typically these movements are assessed using some form of functional movement assessment. This form of assessment is commonly used to screen athletes for dysfunctional movement patterns in attempt to alleviate injury risk through addressing incorrect movement patterns (43). The commercialised Function Movement Screen (FMS) by Cook (43) is by far the most popular screening tool used in sports performance research and is typically synonymous with the term. However a recent survey of practitioners working in high performance sport revealed that the majority of these practitioners preferred to implement their own version of movement assessment rather than the FMS (133). This suggests that the FMS protocol does not meet the needs of the practitioner working in high performance sport.

Based upon the authors personal communication with practitioners and from the published survey results by McKeown (2013), more applicable movements for strength and conditioning program considerations are used as assessment items. For example, the FMS does not assess jumping and landing, or use exercises more typical of strength and conditioning programs to enhance performance. In order for movement assessment to be effective the assessment must not only assess dysfunction across a standardised set of exercises but these exercises must be appropriate for the athletes being assessed and henceforth coached in a systematic approach. The reasons for overlooking the FMS are not well documented. Questions have been raised over the ability of the FMS to characterise meaningful changes in movement quality over multiple testing sessions and the effect of FMS scores on performance improvement(80, 130, 161). The FMS was developed to assess normal function in daily activity and not in the more demanding aspects of sports performance. Anecdotally practitioners are using tools they consider more appropriate for the athletic populations they are working with. Practitioners may also feel the exercises used in the FMS do not, in their experience, align adequately to their coaching approach and therefore will not be useful in informing coaching decisions. There is limited evidence to support the conjecture of these notions in the literature; however this study is the first step in the scientific process to discuss this crucial element of strength and conditioning practice. In order for the movement assessment process to be included in more performance science literature and considered in future research there must be alternative methods discussed and examined. The FMS has initiated this process and has gathering evidence for its use, however it is not yet common practice for professionals in the field assessing athletes to use this method (133). By providing alternative practices, movement assessment can evolve a stronger body evidence to support its use. This study is the first step in the process for an alternative method currently being used in practice by strength and conditioning professionals.

In this study an alternative assessment tool is proposed that addresses the requirement for movement assessment to be specific to athletic populations. The Athletic Ability Assessment (AAA) is proposed as an alternate protocol to the FMS. One of the key differences of the AAA is that the exercises used to assess functional movement are more closely aligned with the foundation movement skills underpinning sports performance. These movements are still assessed in a way that highlights movement dysfunction, but have the advantage of providing a more specific exercise progression template that is better aligned to performance enhancement. In addition to the different exercises used in the movement assessment, the scoring system for each exercise is designed to examine the key components of each movement individually. This provides more information of separate functional qualities across exercises. By examining key components such as trunk control, range of motion, and lower body alignment across a range of exercises, commonalities of dysfunction can be highlighted that provides more insightful feedback to inform the coaching process.

We propose that the AAA be used as an initial screening tool as well as be used to assess changes in functional movement ability over time (by making multiple measurements on the same athlete following a training intervention). In order to confidently assess changes in an individual it is necessary to obtain an estimate of the measurement error arising from the tester(s). The specific objectives of this study were to determine the absolute error with one tester rating the same movements one week apart (intra-tester reliability) as well as determining the error associated with different testers scoring the same performance (inter-tester reliability). A secondary analysis will be performed to investigate differences between real-time assessment and video-based assessment using the same tester.

6.3 Methods

6.3.1. Development of the athletic ability assessment protocol

The foundation movement competencies assessed using the AAA include trunk/hip stability, the ability to squat and lunge and the ability to jump/hop and land in different planes (110, 115). These are commonly considered a foundation for further complex sporting movements is based from. Details of the exercises used in the assessment plus a rationale for each exercise are detailed in Table 1. Each exercise assesses trunk stability, hip, knee, ankle alignment, squat or lunge ability, and ability to jump and land correctly. Many of the exercises will incorporate multiple elements for each exercise chosen.

Exercises and the subsequent assessment items for each exercise were chosen to expose deficiencies in foundation movement patterns required to train and perform competitively in sports (115 , 116, 148). The exercises and items used for assessment were developed over many years of practical application of movement assessment similar to the FMS. Although not collected in one system previously and presented with the rigour presented in this study the use of this type of assessment has been successfully used by professional strength and conditioning coaches previously. This lack of support in the literature again highlights the importance of this study in the development of movement assessment as a critical and valid marker of athlete's ability in sports science. The scoring criteria consist of three main assessment items per exercise. Each assessment point is scored out of three, one being poor, unable to perform specific task; two being inconsistent performance of specific task or slight deviation from ideal; three being perfect performance of specific task in the coaching. The sum of the three assessment points is the individual test score. Maximum score per exercise is nine. Separate scores are given for exercises performed unilaterally. The total of all the individual tests provides the composite score for each athlete. The composite score is out of a possible 117 points. The composite and individual scores can be reported back to the athlete in order to inform them of areas they need to work on in training in the future. The information gathered from the assessment can also be used by the strength and conditioning and medical staff to promote a collaborative effort to concurrently address dysfunction and strive to enhance performance.

6.3.2. Subjects

National level female football players (n=17) (mean ± SD; 22 ± 4 y) completed the AAA as part of pre-season screening for the Australian W-League. No injuries were reported before or during the assessment session. Subjects were provided with a full description of the assessment protocol. Each subject was scored by the primary researcher of this study who had over five years' experience of movement assessment scoring and is an experienced strength and conditioning coach currently accredited by the U.K. Strength and Conditioning Association and the Australian Strength and Conditioning Association (ASCA). All other scorers (n=5) were strength and conditioning professionals with at least 2 years' experience of movement assessment scoring and accredited by the ASCA. The study was approved by the Australian Institute of Sport Research Ethics Committee.

6.3.3. Procedures

Athletes performed the athletic ability assessment protocol in sequential order as described in Table 1 (see Appendix 4). They were given specific instructions on how to correctly perform each exercise, including a verbal description of the scoring criteria. Feedback during the task was prohibited. Time to complete assessment varied depending on group numbers but typically takes from 20 minutes for 2 athletes to 60 minutes for a group of 10. The session was videoed using a standard two-dimensional camera placed in the optimal position for assessment depending on the specific exercise in question. This was either from the frontal or sagittal plane; the overhead squat, single leg squat and walking lunge exercises were filmed from both planes. Scoring was conducted in real-time by the primary researcher and re-scored from the video three months later. The same researcher re-scored the video again after seven days for the calculation of the video-based intra-tester reliability. To estimate inter-tester reliability of the AAA scores, five other testers scored each athlete from the video footage. The testers were given a brief explanation of the scoring criteria for each exercise and were provided with the scoring instructions as per Table 1 (see Appendix 4). Each tester was instructed they could watch each clip as many times as they deemed necessary before recording their score.

6.3.4. Statistical Analysis

The typical error (TE) and intraclass correlation coefficient (ICC) were used to determine the intra- and inter-tester reliability of the composite AAA score. Reliability of the individual test components was also calculated. Calculations were performed using an Excel spreadsheet for reliability of consecutive trials(103, 104). Descriptive data are presented as mean ± standard deviation and reliability estimates are presented with their 90% confidence limits (CL). Pearson's correlation coefficients were used to estimate the agreement between the real-time and video-based scoring procedures.

6.4 Results

The mean score given by the primary researcher (Tester A) in real-time was 76 ± 13 (mean ± SD) points (Table 6.1). The mean score based on video analysis was 72 ± 13 points on the first occasion and 72 ± 16 points on the second occasion. The mean change score for each subject was -0.1 ± 4.2.

The TE and ICC statistics are presented in Table 6.2. The intra-tester TE for the composite score was 2.9 points (90% CL; 2.3 – 4.2 points) with an intra-tester ICC of 0.97 (0.92 – 0.99) (Table 6.2). The intra-tester TE for each of the exercises ranged from 0.4 to 1.1 points. The inter-tester TE for the composite score was 2.8 points (2.5 – 3.3 points) with an inter-tester ICC of 0.96 (0.94 - 0.98) (Table 6.2). The inter-tester TE for each of the exercises was similar to the intra-tester TE ranging from 0.4 – 1.0 points.

Table 6.1. Mean test scores for each tester in each condition (mean ± SD)

	Real time	Video					
Tester	**A**	**A(1)**	**A(2)**	**B**	**C**	**D**	**E**
Composite score	76±13	72±13	72± 16	69±12	69±14	72±13	70±12
Prone hold	7.9±1.0	8.6±0.7	8.5±0.8	8.1±0.6	8.5±0.8	8.6±0.7	8.6±0.6
Side hold (left)	6.4±1.6	6.1±0.9	6.3±1.0	5.9±1.0	6.3±1.0	6.1±0.8	6.3±0.8
Side hold (right)	7.1±1.2	6.3±0.8	6.3±1.0	5.8±1.2	6.3±1.0	6.3±0.8	6.3±0.8
Overhead squat	7.3±1.5	7.2±1.6	7.2±1.7	7.1±1.5	7.2±1.8	7.2±1.6	7.0±1.5
Single leg squat (left)	7.9±1.4	7.4±1.3	7.1±2.3	6.9±1.5	7.1±3.2	7.5±1.1	7.4±1.3
Single leg squat (right)	7.1±1.5	6.8±2.4	7.2±1.5	6.5±2.2	6.6±1.2	6.7±2.3	6.5±2.3
Walking Lunge	7.2±1.7	7.1±1.5	7.1±1.5	7.0±1.3	6.4±1.5	6.9±1.5	6.6±1.5
Hop (left)	7.2±1.5	7.1±1.4	7.3±1.2	6.7±1.3	6.2±1.4	7.0±1.3	6.5±1.4
Hop (right)	7.3±1.4	6.7±1.4	6.8±1.7	6.8±1.0	6.4±1.5	6.7±1.2	6.2±1.4
Bound (left)	7.1±1.6	6.9±1.4	6.6±1.7	6.4±1.3	6.3±1.4	7.0±1.4	6.3±1.5
Bound (right)	7.3±1.6	6.8±1.2	6.5±1.7	6.2±1.2	6.5±1.5	6.6±1.4	6.4±1.4

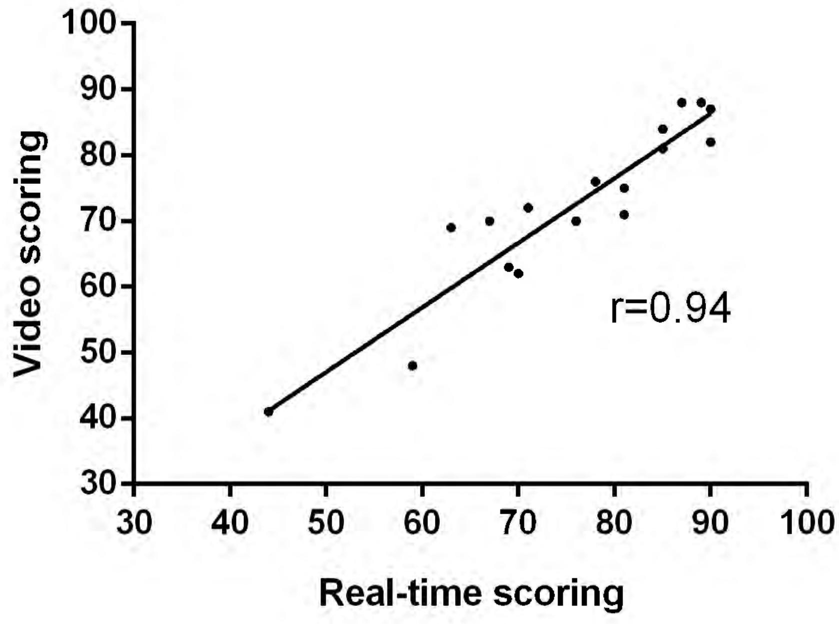

Figure 6.1. Correlation between real-time scoring and video scoring

The correlation between real-time and video scores was very large (r=0.94) (Figure 6.1) with a TE between methods of 3.3 points (90% CL; 2.6-4.7 points). The exercises with the greatest amount of real-time to video error were overhead squat 1.2 points (1.0 – 1.8 points) and walking lunge 1.2 (1.0 – 1.8 points).

Table 6.2. Intra- and inter-tester typical error and intraclass correlation coefficient. Values in brackets are 90% confidence limits

	Intra-tester		Inter-tester	
	TE	**ICC**	**TE**	**ICC**
Composite score	2.9 (2.3 – 4.2)	0.97 (0.92 – 0.99)	2.8 (2.5 – 3.3)	0.96 (0.94 – 0.98)
Prone hold	0.6 (0.5 – 0.9)	0.37 (-0.01 – 0.66)	0.6 (0.5 – 0.7)	0.49 (0.31 – 0.69
Side hold (left)	0.7 (0.5 – 1.0)	0.51 (0.11 – 0.77)	0.6 (0.5 – 0.7)	0.56 (0.38 – 0.74)
Side hold (right)	0.4 (0.3 – 0.6)	0.82 (0.61 – 0.92)	0.4 (0.3 – 0.5)	0.82 (0.71 – 0.90)
Overhead squat	0.9 (0.7 – 1.3)	0.76 (0.49 – 0.89)	0.6 (0.5 – 0.7)	0.87 (0.79 – 0.93)
Single leg squat (left)	0.7 (0.5 – 0.9)	0.89 (0.76 – 0.95)	0.6 (0.5 – 0.7)	0.84 (0.74 – 0.91)
Single leg squat (right)	0.8 (0.6 – 1.2)	0.85 (0.68 – 0.94)	0.7 (0.6 – 0.9)	0.84 (0.74 – 0.91)
Walking Lunge	1.0 (0.8 – 1.4)	0.62 (0.28 – 0.82)	1.0 (0.8 – 1.1)	0.62 (0.45 – 0.77)
Hop (left)	0.8 (0.6 – 1.2)	0.62 (0.30 – 0.82)	0.8 (0.7 – 0.9)	0.70 (0.55 – 0.83)
Hop (right)	1.1 (0.9 – 1.6)	0.57 (0.21 – 0.80)	0.9 (0.8 – 1.1)	0.64 (0.47 – 0.79)
Bound (left)	0.6 (0.5 – 0.9)	0.86 (0.70 – 0.94)	0.6 (0.5 – 0.7)	0.87 (0.78 – 0.93)
Bound (right)	0.9 (0.7 – 1.2)	0.72 (0.43 – 0.87)	0.8 (0.7 – 1.0)	0.72 (0.58 – 0.84)

6.5 Discussion

Movement ability is an often overlooked component of sport performance research and needs to be considered alongside the appraisal of physical fitness and performance characteristics (43). To achieve this, a standardised assessment tool is required. In this study we have introduced the AAA for developing athletes and provided data supporting the scoring testretest reliability. The results showed similar values for intra- and inter-rater reliability (Table 3). Specifically, the AAA score accredited to each athlete varied by approximately ±3 points when scored by the same tester on different occasions, or when scored by different testers. This equates to an error of approximately 4%, which is similar to the TE for inter-tester reliability of the FMS reported by Klusemann (114), but lower than the 9.6% reported for a modified nine-test version of the FMS by Frohm (79). The TE has not been commonly reported in other studies investigating the reliability of movement assessment tools(91, 166, 173). The intra- and inter-rater ICC values in this study were 0.97 and 0.96 respectively, which are better than reported for the FMS (0.75-0.95) (79, 91, 114). Whilst the ICC provides a good indication of the relative reliability of the test scores (whereby high values show individuals are ranked similarly between conditions), the TE is more useful for interpreting the changes in performance from test to test. In this case changes greater than the TE of ± 3 points can confidently be interpreted as 'real' improvements, since the observed change is greater than the error in the test. We recommend that future studies examining the reliability of movement assessment protocols include the TE associated with the scores.

The typical error values were generally similar for all exercises in the AAA, ranging from 0.4 to 1.1 points in the intra-rater analysis and 0.4 to 1.0 points for the inter-rater analysis (Table 2). Whilst we suggest that it is preferable to use the composite score when assessing changes in overall athletic ability, the results indicate that 'real' changes in specific exercises can be revealed when changes of more than 1 to 1.5 points are observed (based on the average width of the confidence limits across exercises). In contrast to values of typical error, the ICC values were not similar across all exercises, with some low (poor) values observed (e.g. prone hold). We attribute the poor ICC values to small between-athlete variation in the scores in these exercises. To illustrate, the individual scores for the prone hold ranged between 6 – 9 points, with 13out 17 athletes scoring the maximum 9 points in the real-time assessment. Such a low variation in scores can mean that a change of only 1 point from test to test can greatly affect the ranking of an athlete within the group, resulting in a low ICC value. This is another limitation of relying solely on the ICC to indicate reliability of movement assessment scores.

Obtaining an estimate of the tester error is the first step in the validation of this new assessment tool. This study was specifically designed to evaluate the random error of measurement introduced to the AAA score by the practitioner(s) doing the scoring. In the intra-rater analysis this error arises from differences in the scores given by the primary researcher (rater A) when scoring the same performance on two separate occasions. Since video footage of the performances was used, this estimate of random error is independent of any biological error (within-subject error) that would be observed if the same athlete completed the assessment on two different occasions. In many performance tests of human performance it is often difficult to separate these error components and therefore only one estimate of error is used to represent both error components (i.e. the error from the tester or equipment and the biological error from the athlete). This is not the case when performance can be assessed post-hoc via video analysis. We have demonstrated that reliable AAA scores can be obtained by a single-rater on different occasions and by different testers performing the same assessment, however there is still need to assess the amount of within-subject error introduced by the same athletes performing the assessment over time. This will enable a more accurate estimate of the changes that are likely to occur from test to test by chance alone. In the case of movement assessments, some reliability studies have included within-subject error(79, 114, 160) while others have not (91, 173). Care therefore must be taken when comparing the reliability estimates between studies that are not comparable in their approach. Assessing the within-subject error is the next step in understanding the magnitude of change in AAA scores that represent real and important changes in individuals.

The last aspect of our analysis included a comparison of scores obtained from real-time and video assessments. The use of video in functional movement assessments has been criticised since video footage does not allow movement to be observed from multiple viewpoints during a single trial by the tester (173). This is in contrast to real-time assessment where the tester is free to view the movement from multiple angles. However real-time assessment only can be labour intensive on a single tester, particularly when dealing with a large squad. Videoing of exercises can alleviate this burden as well as provide video footage for future reference and additional scrutiny. Therefore examining the relationship between the two scoring conditions is important. The analysis of the relationship between scoring in real-time and via video shows a very strong correlation (Figure 6.1). The TE of 3.3 points for the composites score is similar to the other values reported in this study. This analysis supports the use of real-time and video assessment as relatively similar. This clarity in scoring difference provides confidence that an alternative observation will provide reliable results.

Along with obtaining estimates of within-athlete error, further studies have been planned by the current group to explore how changes in athletic ability (specifically improvements in AAA score) relate to improvements in sports performance. In addition to validating the use of the AAA for sports performance research, investigating the relationship between changes in AAA and athletic performance will help to further our understanding of the smallest worthwhile change in AAA that is meaningful for performance enhancement. An exploration of the relationship of AAA scores and injury risk is also needed.

6.6 Practical applications

The AAA provides an alternative movement assessment tool to the highly popular FMS. The AAA has been developed to meet the needs of practitioners working with athletic populations. The results from intra- and inter-tester analyses show that the scores are reproducible based on video and real-time assessments. The typical error in each circumstance is approximately 3 points. Based upon these estimates changes in AAA scores greater than three points can be considered ‘real’. Testers of movement assessment should ideally establish their own TE as illustrated in this study. The analysis of the relationship between intra- and inter-testers and between real-time and video-based assessment provides greater understanding of the scoring differences. This is invaluable for future comparison of results. The components of the analysis for the various scoring conditions have previously not been reported in the literature. These initial stages in the proposition of an alternative protocol of movement assessment are essential for future examination of the relationship between movement and injury risk and sports performance. To date this relationship is inconclusive but is a commonly accepted training concept in contemporary strength and conditioning, more research is needed in this area.

Chapter Seven

The development of a strong foundation in movement ability early in an athlete's development may enable them to avoid as many injuries and also aid in performance. The early development of movement ability has sadly been lacking as junior athletes reaching high performance sport programs are still incompetent at foundation movement tasks. The following paper illustrates the effectiveness of concentrated movement training, as part of the sports training warm up in U14 basketball players.

Development of power in junior basketball players using a movement-based strength and conditioning program

Ian McKeown[1, 2, 3]

David B Pyne[4]

Nick Ball[2]

1. Strength and Conditioning,
   Australian Institute of Sport, Canberra, Australia

2. National Institute of Sport Studies,
   University of Canberra, Canberra, Australia

3. Strength and Conditioning Department, Australian Capital Territory Academy of Sport, Canberra, Australia

4. Department of Physiology, Australian Institute of Sport, Canberra, Australia

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7.1 Abstract

Strength and conditioning training in junior athletes should focus on foundation movement training; however evidence to support this recommendation is lacking. The purpose of this study was to assess the magnitude and time-course of changes in performance and injury predictor indices after six weeks of specific foundation movement coaching in warm-ups prior to training. Ten junior male basketball players (age 13.0 ± 0.6 y; mean ± SD) were assessed for foundation movement ability, countermovement jump (CMJ), squat jump (SJ), drop jump (DJ) and prediction of non-contact injury risk using a repeated tuck jump assessment. Assessment occurred at baseline, week three and week six. Large improvements in movement ability (40%, ±13%; mean, ±90% confidence limits) and injury risk (tuck jump score; -39%, ±38%) were observed over the 6 week study period. Improvements in CMJ power (19%, ±9.4%) and DJ reactive strength were moderate (31%, ± 16%) while changes in SJ power were unclear (9.3%, ±11%). Most of the improvement in foundation movement ability, DJ and tuck jump scores occurred during the first three weeks of training. Improvements in CMJ power were sustained with small changes from both week 1-3 (9.6%, ±7.8%) and week 4-6 (9.8%, ±4.9%). Six weeks of strength and conditioning coaching performed in warm-ups prior to training focussing on movement quality with appropriate progression can substantially improve jumping power and reduce the risk of injury.

7.2 Introduction

Strength and conditioning coaches are often encouraged to develop fundamental movements in their athletes before more advanced skills to improve sports performance. This principle of training progression is based upon recommendations from professional bodies for resistance training in youth or junior athletes (7, 67). Training methods described in the long term athlete development models also state the importance of developing basic fundamental movements and skills during the early stages of athletic development (24, 56).

Functional movement screening can provide valuable information for strength and conditioning professionals to design and coach training programs to correct movement dysfunction observed during screening processes (111). Dysfunctional movements not addressed correlate with an increased risk of injuries and presumably a loss in performance (112). The ability to move efficiently, including jumping and landing, can reduce the likelihood of a non-contact injury (1) but little evidence is available that functional movement ability improves performance (161). Junior basketball has high injury rates, and only American football has a higher injury rate within the U.S. high school system (37). The incidence of injury is higher during competition than practice, and in both male and female high school players' ligament sprains of the lower limb are the most common occurrence (32). A well-designed and implemented strength and conditioning program can reduce the risk of injuries, particularly non-contact injuries, especially in relation to anterior cruciate ligament (ACL) and other lower limb injuries (2, 106).

While there is substantial evidence supporting the effectiveness of neuromuscular training on injury reduction, less evidence exists detailing the degree of performance enhancement of these training programs (176). Significant correlations between performance measured by medicine ball throws and functional movement screen scores have been reported in healthy populations (158), however not for movement screen scores and athletic performance indices in Division 1 college golfers (161). The relationship between functional movement and on-court performance in college-age basketball players (mean age of subjects ~20 y) has been investigated previously (130). Preseason fitness and movement quality (a stiffer trunk, more mobile hips and a longer standing long jump) predicted some aspects of in-season performance (130). Despite the lack of substantial evidence surrounding this area the inclusion of elements of athletic performance, injury prevention, and fundamental athletic skills development are considered essential for a successful program of physical and technical development (43). During adolescence neuromuscular control and strength develop with the natural effects of growth and maturation. Maturation status is often tracked by coaches to inform coaching decisions as it can have a significant impact on athletic performance in junior athletes (109, 121). The time of peak height velocity (PHV) is a common marker of maturity and is utilised in long term athlete development models to orientate biological age on the training pathway (121). No research to date has investigated the impact of such a program of foundation movement ability in junior athletes at age 13 y on injury prediction indices, functional movement skills and athletic performance, or the time-course of changes in the initial stages of the training.

The aim of this study was to quantify the magnitudes and time-course of the change in athletic performance characteristics of junior athletes during six weeks of strength and conditioning coaching, focussing on fundamental movement ability. This information will be useful for coaches, strength and conditioning professionals and administrators responsible for the development of young performers.

7.3 Methods

7.3.1. Experimental approach to the Problem

This single-group study was designed to assess the effectiveness of a 6-week training program, focussing on developing fundamental movement ability, coached by a strength and conditioning professional. Effectiveness of the program was based upon explosive power performance measures, fundamental movement ability and on injury-risk prediction scores in a junior sporting group. The training program was implemented twice a week in preparation for the national championships, immediately after the training intervention finished. Pre, mid- (after 3 weeks) and post- (after six weeks) testing took place before a designated training session. All performance and injury prediction testing were videoed for later analysis by the primary researcher.

7.3.2. Subjects

Participants were all members of an under-14 State Basketball Squad selected by the state appointed coaches as part of the national under-14 program in preparations for the national championships at the end of the season. All subjects were free from injury and had previously participated in a 12-week familiarization process where participants' coaches were part of a pilot implementation project that included practical resources and education sessions to understand and implement foundation movement ability training in their basketball training sessions. Written informed consent was obtained from all subjects' parents or guardians after written and verbal explanation was given to the subjects and their parents or guardians. All testing procedures were approved by the Ethics Committees of the Australian Institute of Sport and University of Canberra.

To estimate the biological maturity of each subject age, body mass, standing height, and sitting height were measured and predicted age from peak height velocity (PHV) determined with a regression equation (137). This method was chosen owing to its measurement accuracy and the non-invasive nature when assessing maturational status in children and adolescents (123). Subjects' characteristics including age from PHV are shown in Table 7.1.

Table 7.1. Subject characteristics, including the group characteristics as split by predicted age from peak height velocity (PHV)

		Bodyweight (kg)	**Height (cm)**	**Age (years)**	**Age from PHV (years)**
Squad Mean	n=11	59.6 ± 9.3	174.1 ± 8.9	13.1 ± 0.6	-0.1 ± 0.8
Pre PHV	n=5	50.4 ± 5.1	165.8 ± 7.4	12.6 ± 0.6	-1 ± 0.6
At PHV	n=6	66.3± 5.1	180.1 ± 4.2	13.4 ± 0.1	0.5 ± 0.2

7.3.3. Procedures

Participants were assessed on their fundamental movement ability using a novel movement assessment protocol. We employed a variation of the popular Functional Movement Screen (FMS) (43) and other movement assessment screens used in strength and conditioning, physiotherapy and athletic therapy. The protocol assesses movement dysfunction for injury prediction and prevention and informs coaches of programming considerations to enhance performance. The fundamental movements' assessed included body weight squats, lunge and return, countermovement jump and push up. These exercises were chosen to highlight lower body function, both double and single-leg, the ability to produce force (i.e. jump), and for trunk control and upper body strength. The coaching points and scoring criteria are described in Table 7.2. The typical error for intra-tester reliability in movement ability total score for this study was 2.6%.

Jump performance was measured using a countermovement jump (CMJ), concentric-only squat jump (SJ) and a drop jump (DJ). For all types of jumps, subjects performed 6 maximal-effort trials with the mean score used for statistical analysis. For countermovement jumps, subjects were asked to jump as high and as fast as possible. To eliminate the contribution of arm swing, the subjects held a light wooden pole across shoulders. A self-selected depth of counter movement was used. For squat jumps, subjects held the wooden pole across their shoulders, and began the trial with knee flexion at approximately 110° and an upright torso. Subjects were instructed to maintain that position for approximately 3 seconds then cued to jump as high and as fast as possible with no countermovement. All trials were analyzed visually by the investigators for any small amplitude countermovement as recommended (171). Mean concentric power during CMJ and SJ was measured using a linear position transducer (GymAware Version 4; Kinetic Performance Technology, Australia). The typical error for CMJ in this study was $2.2 w.kg^{-1}$ and $2.8 w.kg^{-1}$ for SJ.

Drop jumps were performed off a 30 cm box on to a timing mat (Speed Mat, Swift Performance Equipment; Australia). Subjects were instructed to jump as fast and high off the mat on landing; with values for contact time (s), flight time (s) and jump height (m) recorded. The reactive strength index (RSI) was used to describe the interaction of contact time and jump height (RSI = contact time/jump height).

Table 7.2. Movement Ability Assessment Criteria. Athletes are instructed to attempt the number of repetitions as stated per exercise. Assessment is based on how well each athlete exhibits movement through the exercise according to assessment criteria. Athletes are also instructed to stop if the form is consistently poor and/or dangerous.

Exercise	ASSESSMENT AREAS	3 = Good	2 = OK	1 = Needs work
Bodyweight Squat Hands on head, elbows up and back x10 reps	Upper body position	Elbows high and in line with ears Shoulders back and down	Unable to keep elbows high and inline **OR** unable to shoulders back and down	unable to maintain position
	Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every rep	Inconsistent form with some perfect reps **OR** minor misalignment on all reps	Alignment poor throughout
	Depth	Crease of thigh below knee (below parallel) while maintaining neutral spine for all reps	Depth beyond parallel for some but not all reps	Not able to achieve required depth for any reps
Lunge and Return Hands on head, elbows up and back Bodyweight x 10 steps	Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every rep	Inconsistent form with some perfect reps **OR** minor misalignment on all reps	No perfect reps
	Hip Control	Hips do not roll or rotate through steps	Inconsistent form with some perfect reps **OR** minor loss of control on all reps	A lot of movement through hips
	Trunk Control	Control of trunk - no leaning sideways or forward/backwards - trunk flat and strong throughout	Inconsistent form with some perfect reps **OR** minor loss of control on all reps	Forced lumbar extension or lack of trunk control during force production
DBL CMJ + Land For Height x 5 reps	Triple Extension	Fully extends through hips/knees/ankles to produce force for all jumps	Just short of full extension	Lack of triple extension
	Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle on takeoff and landing	minor misalignment, slight lack of control on takeoff **OR** landing	Hip/knee/ankle alignment incorrect, poor control
	Power Position on Landing	Lands in power position/quarter squat	Slightly too deep squat on landing. Not solid upper body position	Landing position much too deep. No control through trunk - too mush flexion or extension.
Push up Attempt 5 reps	Upper body control	Shoulders back and down Shoulder blades flat aginst back	Some shoulder deviation from start position Shoulders blades sometimes not flat against back some readjustment allowed	Cannot get into good start position cannot readjust when in movement
	Body Control	Body straight and solid throughout all reps	Some readjustment or movement from start position	Poor body control and/or alignment for all reps
	Complete reps	>5	3-4	<2

A repetitive tuck jump exercise was used for the identification of lower extremity technical flaws closely associated with serious injury (140). The tuck jump test has been developed from laboratory-based prediction models of injury and provides as accurate a representation of movement deficiency as a field-based test (145). Each subject performed repeated tuck jumps for 10 seconds, which allowed the coach to visually grade the outlined criteria. To further improve the accuracy of the assessment, a standard 2-dimensional camera in the frontal and sagittal planes was used. The subject's technique was subjectively rated as either having an apparent deficit or not. The deficits were then tallied to give a final assessment score (140). The typical error for intra-tester reliability in the tuck jump scoring in this study was 1.1 points.

Training Program

Based upon the scores from the movement ability, jump performance and injury prediction risk from the initial assessment period, a training program was developed to address any identified deficits in ability across the subject group. The training program was delivered prior to two basketball sessions per week as the warm-up to the main training session, and took approximately 15 minutes to complete. The training program included elements of flexibility and mobility, jumping and landing technique, squatting and lunging progressions, and trunk stability/upper body control (Table 7.3). Progression throughout the program was made through an increase in complexity, speed, amplitude or duration of the exercises. Total training volume for the warm-up remained similar throughout the program due to time restrictions before training sessions.

Table 7.3. Training Program. Sessions completed prior to basketball training as a 5 min circuit undertaken three times (total time 15 min). The program changed after every third session.

	Sessions 1-3 **Weeks 1.1-2.1**	**Sessions 4-6** **Weeks 2.2-3.2**	**Sessions 7-9** **Week 4.1-5.1**	**Sessions 10-12** **Week 5.2-6.2**
Mobility – Hip/Hamstring/Calf	Calf/Cobra/Caterpillar x5el/x1/x1 – x3 Lunge/Hip Lift x3el	Squat/Stand/Caterpilla r/Cobra x3 Lunge/Hip Lift and Rotate x3el	Lunge/Bend/Hip Lift/Rotation x3el	OH Lunge/ Hip Lift/ rotation/ Caterpillar/cobra x2
Squat - technique and leg strength	Squat hands in front + pause on last one x10 +10s hold	Squat – Hands behind head + pause on last one x10 +10s hold	Squat - hands behind head + Hold 10x3s	OH Squat 10x3s
Lunge - technique and leg strength	Split Squat x10el Backward Lunge x10el	Bk Lunge + High knee pose x6el Bridge and hold at top x20	OH Back Lunge x8el Sl Bridge hold x10s el	Back Lunge and rotate x6el Sl ¼ Squat x6el
Land - Muscle coordination/co-contraction	Speed Squat and Drop x5	Jump and Land x10	Long Jump x6	Long jump to high jump x5
Jump – Power Development	Small pogo's x10s	Pogos x15	Lateral Pogos x10	Compass jumps x10s
Upper Body/Trunk	Prone scap push ups x10 Prone rotations (x5s each way) x2 rotations	Prone Rotations + Push Up x5s ew x3 push ups	Prone Rotations + Double Push Up x5s ew x3 push ups	Side Holds with x3 push ups

7.3.4. Statistical Analyses

Performance measures in Week 1 (Pre), Week 3 (Mid) and Week 6 (Post) are presented as mean ± standard deviation. All data was log transformed to reduce non-uniformity of error and changes derived via back-transformation as a percent (101). Standardized changes of <0.20, <0.60, <1.2, <2.0 and >2.0 were interpreted as trivial, small, moderate, large, and very large effects, respectively (27, 105). To make inferences about the true (large-sample) value of an effect, the uncertainty in the effects are expressed as ± 90% confidence limits. A substantial change in performance was accepted when the likelihood of a positive effect was greater than 75%, where the smallest standardized change was assumed to be 0.20 (41). An effect was deemed unclear when its confidence interval spanned simultaneously both positive (0.20) and negative (-0.2) thresholds.

7.4 Results

Large improvements in movement assessment (40%, ±13%; 1.6, ±0.6) (mean, ± 90% confidence limits; standardized change ±90% confidence limits) and tuck jump scores (-39%, ±16%; 1.9, ±1.2) were observed over the 6-week study period. Moderate improvements in CMJ power (19%, ± 9.4%; 0.77 ± 0.40 and DJ RSI (31%, ±16%; 1.0, ±0.6) were recorded over the same time period. Changes in SJ power were unclear (9.3% ± 11%; 0.35, ±0.41).

The improvements in movement ability, tuck jump, and DJ RSI were all generally two- to-three-fold larger from Week 1-3 than Week 4-6. For example, there was a moderate improvement in movement ability score after 3 weeks of training (24%, ±15%; 1.0, ±0.69), compared to a small improvement from mid to post testing (9.5%, ±5.6%; 0.44, ±2.26). Similarly an initial, moderate improvement was observed in DJ RSI (29%, ±17%; 0.93, ±0.59) while the improvement during weeks 4 to 6 were small (6.3%, ±9.1%; 0.23, ±0.33). A large change (-36%, ±23%; -1.7, ±0.8) in the tuck jump scores was observed after the first 3 weeks of the intervention. This rate of improvement was not sustained through the second half of the intervention. Effects within the second half of the intervention were unclear (-8.3%, ± 24%; -0.33, ±0.80).

Improvements in CMJ power were similar in magnitude over the duration of the study i.e. small changes from baseline to mid-test (9.6% ±7.8%; 0.41, ±0.33) that were replicated from mid- to post-test (9.8%, ±4.9%; 0.42, ±0.22). In contrast SJ power changes over both the first (0.6%, ±8.2%; 0.02, ±0.31) and second (0.9%, ±9.7%; 0.03, ±0.36) three week blocks were unclear.

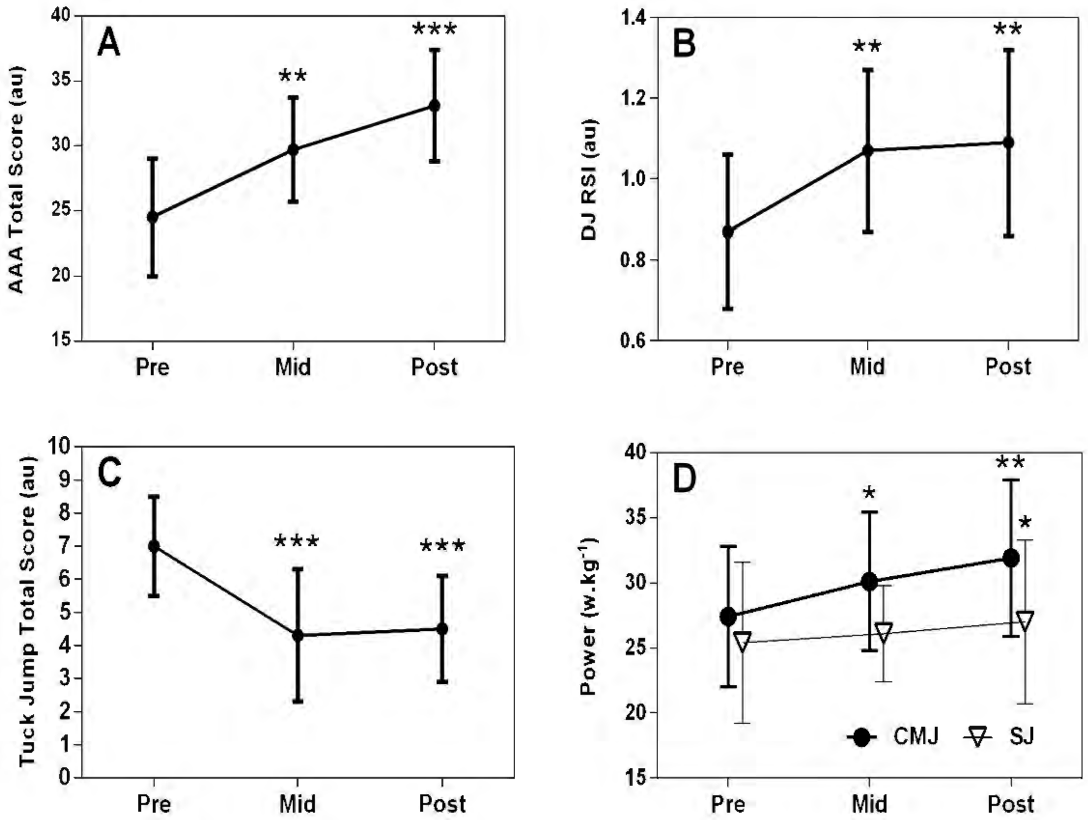

Figure 7.1. Changes in mean ± SD for (A) Movement ability total scores; (B) DJ reactive strength index (RSI) ratio; (C) Tuck jump total score values; (D) Power values for CMJ and SJ. * = Small change, ** = Moderate change, *** = Large change

7.5 Discussion

Analysis of the time-course of changes in athletic performance revealed early improvements in movement ability and injury prediction scores with moderate changes evident after three weeks of training. After six weeks of training large improvements in movement ability and injury prediction scores coincided with moderate changes in CMJ and DJ performance. These results provide evidence to support the implementation of well-designed warm-up for junior athletes administered by a strength and conditioning professional. Warm-up prior to sports training should address improvements in overall athleticism, correct movement dysfunction and be used as part of a holistic injury prevention program.

The large improvement in movement ability after 6 weeks indicates that a short intensively coached training program can yield substantial changes in the quality of fundamental movement ability in junior athletes. Moderate changes after only three weeks suggest improvements can be seen quickly after only a short period of time in this cohort. The magnitude of the changes (~10-30%) observed in junior athletes after three and six weeks of the training program confirm the effectiveness of a movement-based warm-up prior to sports training. Longer more intense training interventions designed as stand-alone sessions including strength training improved total FMS scores by 14% ± 5% (mean ± SD) in supervised junior basketball players (114). Other research into changes in functional movement ability has shown no significant changes post intervention of total scores between groups using FMS (80). Improvements of 10-30% in athletic movement ability seen in six weeks suggest that during the formative years of adolescence larger improvements can be obtained than typically observed in adult athletes (80, 111). Addressing movement dysfunction at an earlier stage in an athlete's development may result in long lasting and meaningful changes in movement quality potentially reducing risk of injury and promoting greater improvements in performance (43, 177).

Moderate improvements in CMJ and DJ performance accompanied the large changes in movement ability. These improvements are greater in magnitude than previously reported after studies in junior populations of similar duration. A review of studies investigating changes in vertical jump height after resistance training interventions reported improvements from 5 to 25% (96). Small 5-8% improvements in jump height have been found after resistance training in junior basketball players (114, 155). No resistance training except for basic bodyweight exercises focussing on movement competency were involved in the present study. Substantial improvements in CMJ power and DJ can be achieved without the need for extra training and within a relatively short period of time: 2 times per week for approximately 15 min per session. This type of program can provide junior athletes with a strong foundation in fundamental training and sports skills underpinning improvements in performance in the post-adolescent and early adulthood period.

SJ performance did not improve at the same magnitude as CMJ or DJ throughout the study period. Changes in SJ were unclear and show only a possible trivial improvement. Due to the nature of the training program used in the warm-up, concentric-only performance will not have been trained to the same extent as other elements of assessment. Movement control was the primary focus of the training program with a secondary focus on jumping and landing, specifically utilising the stretch-shortening cycle. A long term program of athletic development should first concentrate on laying a strong foundation of movement ability before advancing towards more complex movements or adding resistance. The program and the subjects in this present study are at the start of this pathway. Improvements in SJ would be expected with the introduction of more strength-based work and increasing complexity of exercises (132). Such advancements in programming would occur for this group at some stage after the current phase of training is complete and subjects are sufficiently competent to continue.

The large improvement in tuck jump scores after three weeks indicate that concentrating on movement quality and investing in high quality coaching, in the early stages of development, can enhance injury resiliency and performance. The use of training interventions to improve injury resilience is a popular topic in sports that have a greater risk of non-contact injuries, such as anterior cruciate ligament (ACL) rupture (2, 140). Integrated neuromuscular training programs prescribed for injury prevention typically include strength training, landing and take-off training, and other proprioceptive tasks. Commonly, improvements in tuck jump scores and other injury predictor tasks have been reported (98, 113, 148), however performance enhancement with these training programs has typically not been considered. One study failed to identify substantial improvements in a range of jumping tasks after a 10-week neuromuscular training intervention – the so-called 11+ program (176), and no performance measures were reported (174). The absence of performance measures in neuromuscular training studies limits the practical application for athletic development programs. It is essential that performance enhancement be considered alongside injury prevention.

The chronological age of the group and their biological maturity (predicted age of PHV) have previously been associated with large improvements in strength (66, 96). However, gains in strength are typically observed after resistance training and not through improvements in foundation movement ability. Training foundation movement ability, including jumping and landing yielded substantial improvements in the athletic performance underpinned by strength without the need for a resistance training program. The short period of intervention in this study would not provide adequate time for morphological effects of maturation and training to take place. The changes in performance across the training intervention and between week three and six are likely to be neural in nature (90). Neural adaptations such as increased recruitment of muscle fibres, increased speed of recruitment, improved synchronisation of muscle recruitment, and decreased muscle inhibition, could account for large increases in strength in novice and junior athletes (60). Improvements in movement ability scores could be partially explained by enhancement in motor control strategies and movement coordination. Neural adaptation may also enhance movement ability and other aspects of performance, not only gross measures of strength. Improvements in athletic qualities during this stage in biological maturation can be made, while striving for improvements in traditional performance measures. Further research is needed to quantify the time-course, retention and subsequent trajectory of future adaptations in the months and years following a structured training program.

Our study suggests incorporating movement focussed training in warm-ups before training sessions can improve functional movement quality of junior athletes, performance and reduce the risk of injury. We acknowledge the shortcomings of the single-group design of this study. However we consider that the six week intervention is likely too short for any substantial morphological changes. The changes observed during this short study are likely to be in response to training rather than factors of maturation.

7.6 Practical application

Warm-up drills prior to sports training should be well designed, coached and focused on movement quality across a range of exercises deemed necessary for correct execution of sports-specific skills. Substantial 10-30% improvements in movement ability can be obtained after just three weeks of coaching in junior athletes aged 12-14 y. Prior to the use of formal resistance training programs, coaches should address fundamental movement skills. This approach should reduce the risk of injury and enhance performance in explosive strength tasks in junior athletes around PHV. Implementation of a simple movement assessment that can easily be incorporated into the warm-up is recommended. Movement assessment took 20 minutes to complete, one hour for the squad. Standardized movement assessment can be used to guide exercise progressions and technical correction of any identified movement dysfunction.

Chapter Eight

8.1 Thesis Summary and Conclusions

The aim of this thesis was to provide a body of work that improves our understanding of power development and movement ability in junior athletes. Due to a lack of research into power development in junior athletes two separate studies were conducted to gain a better understanding of how these athletes respond to strength and power training. We were particularly interested in furthering our understanding of the responses of pre-elite athletes as they enter a full-time training program at the national sports institute. Detailed information regarding the nature of strength and power adaptations was sought and in particular, we were interested in describing the rate or time course of these adaptations. Such a comprehensive description of changes in strength and power in these athletes is not yet available since previous studies investigating performance in junior athletes have typically only reported the post-pre changes in jump height. By profiling strength and power characteristics on a weekly or fortnightly basis we found that improvements in power precede changes in jump height. This further illustrates the limitations of relying on a single measure of strength and power expression (51, 52). The time course of improvements in strength and power characteristics for netball players presented in Chapter 4 revealed moderate to large improvements within the first seven weeks of training. These early improvements are likely a response to neural adaptations (i.e. an increase inter-muscular coordination, muscle fibre activation, muscle fibre recruitment and firing frequency) that are common after the introduction of a new training stimulus. These improvements however did not continue, with only trivial changes observed during the second phase of the study. These findings imply that the training prescription was only effective in eliciting neuromuscular changes associated with familiarisation. Alternatively, the rate of adaptation in this group may have been diminished due to the competition schedule which affected training consistency. The rate of the initial improvement reported in this study should be considered by practitioners when designing training programs for junior athletes to ensure continued strength and power adaptation beyond the initial learning phase.

The large initial improvements were not as evident in the basketball and volleyball players studied in chapter 5, although small to moderate improvements were noted by week 10. The improvements in CMJ power of the volleyball players were similar in magnitude to improvements exhibited in elite athletes over much longer time periods (131, 172), adding to evidence suggesting that a law of diminishing returns affects the rate of adaptation as training experience increases (134). Another important finding from this study, was that the post-pre analysis failed to reveal a range of substantial improvements that largely affect the interpretation of the training outcomes. This was exemplified by a trivial post-pre difference in squat jump power in the volleyball group, overlooking the clear improvements indicated at other time points via the time course analysis. The results presented in chapters 4 and 5 highlight that important information relevant to differing rates of adaptation throughout training phases, and differences in the response of strength and power indices is reliant on frequent assessments. Relying on post-pre analyses limits our understanding of the true response to strength and power training.

As seen in both studies moderate to large initial improvements in junior athletes entering a high performance training program are achievable. The major challenge in prescribing training for strength and power development after the initial adaptations have occurred is in applying more advanced training methods for further improvements in junior athletes. A large evidence-base exists regarding the application of advanced training methodologies for elite athletes; however well-developed movement ability is a pre-requisite for handling the loads, the forces, and the complexity of the movements involved. In junior athletes, movement ability should be wide ranging and diverse (6, 20, 56, 121). However, professional experience indicates that these fundamental movements are not well established prior to sports specialisation and entry to high performance sports programs. Therefore emphasis on improving fundamental movement ability in junior athletes is likely, in order to progress to advanced training methodologies. To effectively assess current movement ability as well as improvements following training interventions robust movement assessment tools are required.

The Functional Movement Screen (FMS) (1, 43-45) was developed for this purpose however responses to the survey conducted in chapter 3 indicated that the majority of practitioners working with junior athletes are not satisfied with the FMS. Instead most have opted to develop custom movement assessment protocols to suit their needs. The lack of scientific validation of these protocols however, limits their usefulness in performance research settings. To accommodate this need, the Athletic Ability Assessment (AAA) was developed. The AAA uses movements closely aligned with the foundation movement skills underpinning sports performance, while highlighting movement dysfunction. An advantage of the AAA over the FMS is that it provides a more specific exercise progression template that is better aligned to performance enhancement. In Chapter 6, an examination of the AAA reliability was undertaken as obtaining an estimate of the tester error was identified as the first step in the validation of this new assessment tool. The AAA score accredited to each athlete varied by approximately ±3 points when scored by the same tester on different occasions, or when scored by different testers. This equates to an error of approximately 4%, which is similar to the typical error (TE) for inter-tester reliability of the FMS reported by Klusemann (114), but lower than the 9.6% reported for a modified nine-test version of the FMS by Frohm (79). Knowledge of the typical error is important when interpreting the changes in performance from test to test. For the AAA changes greater than the TE of ± 3 points can confidently interpreted as 'real' improvements, since the observed change is greater than the error in the test. We recommend that future studies examining the reliability of movement assessment protocols include the TE associated with the scores.

Improvements in movement ability, in relation to physical fitness and performance characteristics, have mostly been overlooked in sports performance research. To begin this exploration, a 6-week study investigating the effect of a movement-based warm-up on movement ability (assessed using a modified AAA) and changes in power in young athletes (Under 14) was conducted. Movement ability was assessed using a modified AAA from chapter 6 to align to the appropriate foundation movement skills required at this early developmental level of athlete. The results indicated that a short amount of time concentrating on movement before sports training improves movement ability (40%), power (19%), and decreases injury risk (39%). This study provides coaches with practical recommendations for ensuring their athletes are equipped with a strong foundation in movement ability prior to sports specialisation. This study provides an indication of the impact movement ability may have on subsequent performance tests. This study, along with the development of the AAA, was provided as a basis for future research investigating various methods to improve movement ability and the relationship these changes have on other performance indices.

This thesis has provided previously unreported details of the typical profile of strength and power adaptations when junior athletes enter a high performance sports program. The methods, which utilised a range of jump types, with a high frequency of assessment, provide greater insight for further our understanding of the challenges in prescribing effective strength and power training for this population. The introduction of a novel and athletic-specific movement assessment tool in this thesis has laid the foundation for future discussion and examination of the relationship between power, and subsequent sports performance, and movement ability. Prior to this thesis this relationship has not been explored, therefore adding an original and significant contribution to the field.

8.2 Practical Applications

Based on the findings presented in this thesis, the following practical recommendations are made for practitioners working with junior, pre-elite athletes to develop strength and power.

- Frequent monitoring of performance variables using different jump types should be used to inform the coach when a plateau has been reached in performance and the training stimulus needs adjusting. Too long a period between assessments within a training phase may result in important changes being missed, or interpreting the changes incorrectly.
- Jump height is not as sensitive to change as power and therefore where possible instrumenting jumps to measure power should be preferred.
- Improvements in strength and power occur earlier in pre-elite athletes than generally reported for more senior athletes. This finding has implications for training prescription, especially in the early stages of systematic strength and power training.
- The AAA provides an alternative movement assessment tool to the highly popular FMS and can be used reliably to assess changes in movement ability.
- Testers of movement assessment should ideally establish their own typical error to ensure it is within acceptable limits. Based on initial findings presented here these limits are approximately 4% however, more work is required to confirm this value.
- Short, concentrated warm-up drills that are well-designed, coached and focused on movement quality can improve movement ability alongside improvements in performance and reduce injury risk.
- Prior to the use of formal resistance training programs, coaches should address fundamental movement skills.
- Standardized movement assessment can be used to guide exercise progressions and technical correction of any identified movement dysfunction.

8.3 Future research

The research presented in this thesis has broadened our understanding of movement ability and power characteristics in junior athletes and how they may influence each other. The AAA was developed to enhance opportunities to explore this relationship even further. The following areas require further investigation.

- An estimation of the magnitude biological variation associated with movement ability is needed to further understand the typical error associated with movement ability. This estimation, along with an understanding of the smallest worthwhile change in performance, should be used in future research to define the magnitude of meaningful changes.
- More study is needed to understand the relationship between changes in movement ability, strength and power characteristics, and subsequent sports performance. This relationship may be different in populations differing in age, training experience, sporting backgrounds, gender, and other performance characteristics (e.g. maximum strength).
- Is there a detraining effect to movement ability and does detraining impact injury risk?
- Are there sports requiring a greater foundation in movement ability?
- What is the limit to movement ability in relation to sports performance; is there a law of diminishing return?
- Does a greater rate of early adaption to training predict greater trainability later in an athlete’s development? Can this response be used in talent identification?
- Can deficiencies in movement ability in athletic populations predict specific injury sites? Can improvements in movement ability decrease injury risk?

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Appendices

10.1 Appendix 1: Conference Abstract

McKeown, I. **"Athletic pathway for developing soccer players: how to apply the theory of long term athlete development models to the practical strength and conditioning environment"**

Australian Strength and Conditioning Association, International Conference on Applied Strength and Conditioning, Podium Presentation Gold Coast 2011

Introduction

Over recent years the implementation of Long Term Athlete Development (LTAD) models has been widespread across all Australian sports. Balyi's Model of Long Term Athlete Development (LTAD) (23) has been the most popular model that has been used within National Sporting Organisations (NSO). This model is not without its critics with authors such as Côté (57) and Ford (74) producing not only critical reviews but actual alternatives to this most popular model. The Developmental Model of Sport Participation (56) is a fine alternative to Balyi's work.

The problem with such models is that they are largely theoretical and often do not provide strong, exact examples of practical application. In an organisation or national sporting organisation (NSO) often the models proposed do not fit the structure that is in place, these structures are largely fixed due to a plethora of historical and political reasons. To apply such models as Balyi's LTAD exactly to any real organisation or NSO is unreasonable, therefore the models' underlying principles should at least be considered and an individual model for each unique environment developed.

Kelvin Giles and colleagues have addressed the gap between theoretical and practical application of LTAD with the development of recent coaching tools such as the Movement Dynamics streams for exercises and movements. The work of Giles, for example, draws upon extensive experience in the area of athlete development. Drawing on popular physiotherapy and movement assessments to provide progressions of exercises that can be subjectively assessed to enable coaches to programme and coach accordingly, for each athlete along their sporting pathway.

Within the ACT Academy of Sport (ACTAS) each sport has its own pathway towards performance. For each pathway within ACTAS there is a strong physical or athletic ability stream. At each level of the pathway, the athletic qualities expected should align to the mechanical and technical load that is required at each level of training and competition.

As a marker of assessment for these levels, critical movements/exercises are assessed. The criterion for each assessment is focused on movement and control perfection throughout the body. As the pathway progresses so does the specificity for each sport along with the complexity and/or difficulty of the movements. This is commonly achieved through increases in load, introducing more complexity to movements, and/or demanding greater velocity of movements. The pathway incorporates, and should be aligned logically, with Talent development programmes, through to Senior International competition demands and performance. The pathway for each sport is devised through a long and robust consultative process, including athlete development experts, sports coaches and sports medicine professionals. This enables a holistic approach of athletic development of each player to be charted.

Within soccer, as is typical of most sports, there is a conflict in beliefs over how to best prepare players. The Coach will tend to lean towards technical efficiency and broad definitions of physical traits. The guidelines from Football Federation Australia (FFA) favour all development of the player to include ball skills particularly specific to soccer. This can cause controversy as to develop the technical ability of a player it is prudent and logical that they must first have the physical ability to perform such skills.

The Women's Football programme at ACTAS has striven to incorporate all aspects of national guidelines along with individual coaching philosophies of our, into the athletic pathway that has been developed. The full backing and cooperation of all service providers and coaches within the programme has made such a structure possible. The following is a brief explanation of the pathway as far as it has evolved to date; how the pathway has been delivered; challenges for the further evolution of the process and finally, the advantages of applying such a structure to other sports and organisations.

Athlete Pathway for ACTAS Women's' Football Programme

The pathway that has been put in place at ACTAS for the Women's Football Programme is specific to its' unique set of circumstances, from player age, coaching contact times and competition requirements. This set of circumstances has had to be considered consistently through the evolution of the system that is now in place. The system in place is fluid and is under constant review; as often is the case, players graduate or move on from a programme and a new set of players with different backgrounds and abilities enter the programme. See Figure 1 for an illustration of the pathway. The chart follows the different levels, relating the levels back to ideal playing levels and also providing a short summary of the key coaching focus' during the various stages.

At present there is a foundation level of athletic ability that is generic across the whole population of athletes at ACTAS; the main aim is to produce athletes with excellent qualities of general athletic movements including squatting, lunging, pushing, pulling and bracing. Progression from Foundation level will not be determined by age but by ability to meet the majority of the assessment criteria for each of the exercises/movements.

The progression from Foundation is through to Specialisation. The Specialisation level is defined by the concept that athletes are starting to specialise in a chosen sport and the physical requirements of technical proficiency and training load will increase exponentially (56). Assessment at this level considers these increases and therefore demands movement ability to coincide with this. This level also introduces the concept of maximal effort in training and competition. Maximal effort alludes to maximal strength and power gains being demanded in the training environment, not only in the gym but through training and conditioning and transferring this new found capability to competition.

The final level of the pathway is progression into a performance focussed, senior international level, in this case Matilda's level. If the player has progressed through the levels to date then at this level the player should be excellent from an athletic stand point. Years of considered training and coaching will have produced a physically robust athlete who can perform at mechanical and physiological limits during training that will transfer into performance in competition. At this stage it is prudent to re-assess movement to ensure that skill levels are acceptable, but the focus will very much be based on how to maximise performance on-pitch; therefore specific projects may be put in place for very targeted elements of performance that the Sports Coach believes will result in transfer to competition.

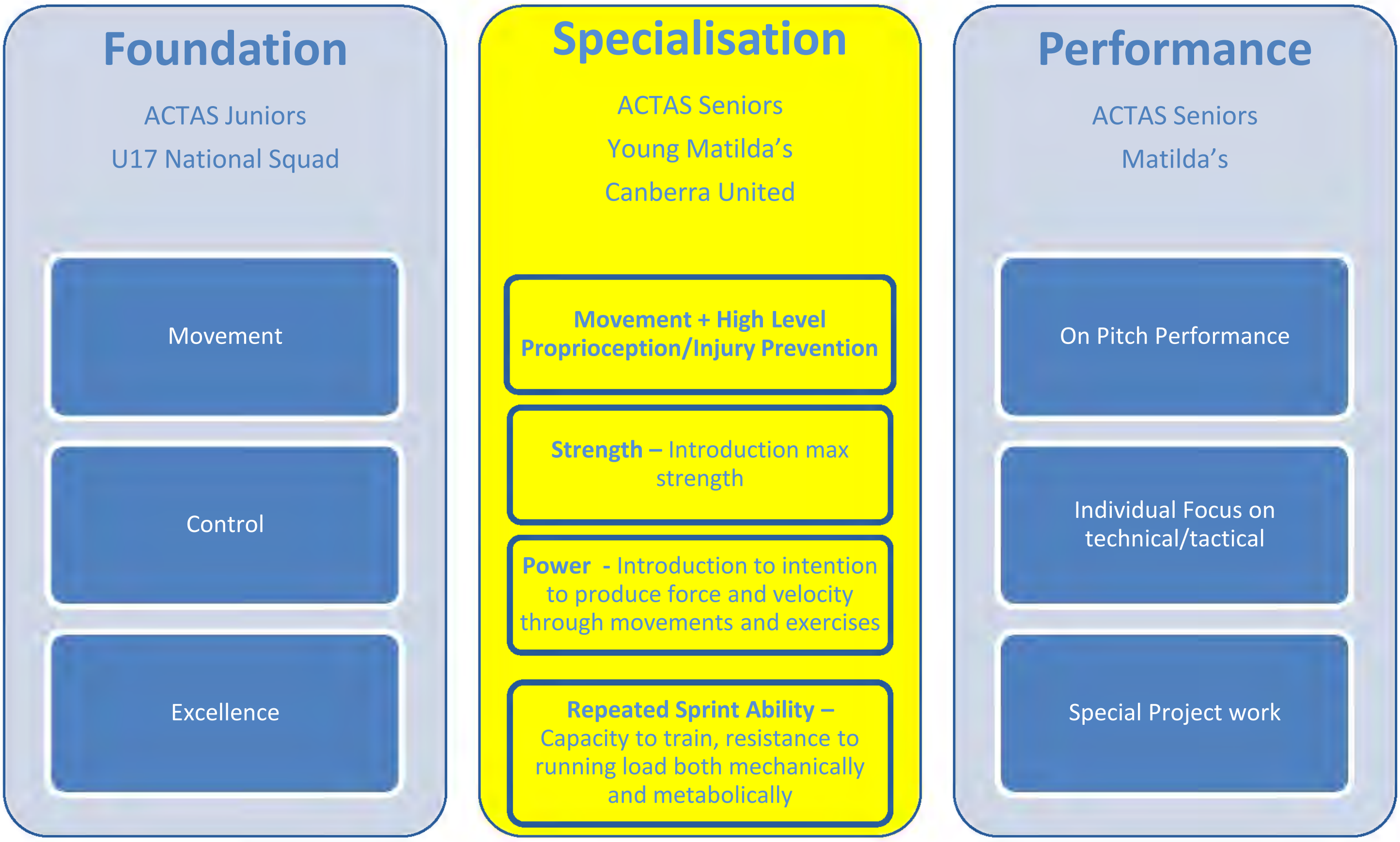

Figure 1; Athletic Pathway for Women's Football

The assessment of the players at their specific level in the pathway tends to happen every 4-6 months; this is dependent on the competition programme. Alongside the athletic ability, each player is given the opportunity to self-reflect on their playing ability through a questionnaire and individual meetings with the Sports Coach. Constructive feedback and practical interventions and follow up assessment are driven by the Head Coach in conjunction with the Sports Psychologist.

By developing the process of a long term pathway for a sport or programme the service providers within the programme can clearly map their interventions and create a strong working model for a multi-disciplined approach to athlete development. From a Strength and

Conditioning point of view this enables the plan or periodisation of each player's individual programme to focus on clearly defined goals. This is nothing new but by shifting the focus towards athletic development from historical measures of absolute strength and power, there is an amalgamation of concepts relating to long term athlete development and assessment into a practical model.

Apart from determining a strong plan for the general structure of periodisation of the player by creating a model similar to that described here, the actual session content can now achieve a new sense of clarity as all training exercises can be related back to the assessment criterion. This type of athlete education not only provides a greater understanding of the training programmes but provides an opportunity to further develop self sufficient athletes as the coaching points and assessment of exercise are one and the same.

With the success of such a programme the players within the programme graduate to US College systems or other National programmes. The intention is that the knowledge and experience gained from such a programme has been instilled in the player therefore they are self sufficient and technically proficient athletes that can adapt to any training environment.

Other positives from spending the time to develop such a structure are that the training philosophies of the coach are consistent and now evident throughout the programme, this has provided an excellent environment in training where full understanding of themes such as; the physical abilities giving a platform for technical inefficiencies to be addressed.

Future Challenge

The main challenge for the implementation of such a pathway is dealing with the movement and physical ability level of the new recruits to the programme. The poor standard ability of new players into the programme is the result of many factors; mainly the lack of exposure to the deliberate practice of movement skills and technical advancement. The level of difficulty for the pathway must not be compromised as this lowers the expected level of athletic ability and should be seen as a lowering of the bar, such actions are poisonous to the ideology of athletic pathways. Therefore, it is our responsibility to educate the coaches and parents of those players aspiring to reach ACTAS level.

To address the issue of lack of apparent physical ability, the level of expected minimum competency of movement must be well communicated, this must include information and an educational process of all the key stakeholders e.g. sports clubs, team managers and coaches, parents and players. The minimum level of competency at ACTAS is the Foundation level. From here the coaches of the developing players must be given the appropriate tools to then impact on their young players. This would include educational workshops, exercise suggestions and implementation plans; such as using movement-based warm ups.

Practical Application

Developing a specific athletic pathway for the particular environment that the Strength and Conditioning professional is involved in will help with;

- *Strategic/Organisational Direction* – will provide a clear plan of progression that encompasses specific levels of development on-field with what needs to take place in training.
- *Coaching collaboration* – not only from within a Strength and Conditioning Department but such a system will provide a collaborative working environment for the Sports Coach, the Strength and Conditioning Coach and any other service providers for the sport or individual.
- *LTAD* – an Athletic Development pathway provides everyone involved with a clear and practical plan that includes the sound concepts of the theoretical models of LTAD.
- *Exercise Selection* – a good pathway of assessment and expectation will determine the progressions of exercise selection, providing the player with a clear map of what they need to do to become a Performance-Level player.
- *Athlete, Coach and Parent Buy in and Accountability* – providing education of the pathway to all involved will enable all stakeholders to fully understand the process and how they can best influence the progression of the player. Historically, contentious issues surrounding parental involvement and coach intervention can now be mostly avoided by having a clear and transparent system that everyone is free to contribute to.

10.2 Appendix 2: Conference Abstract

McKeown, I. & Ball, N. **"Positive effect of strength and conditioning training on jump performance variables in elite netball players"**

UKsem Annual Congress, Poster Abstract. London. 2011

The aim of this investigation was assess improvement over 4 months of training in jump performance variables across a range of typical jump tests used in strength and conditioning for elite netball players in the Australian Institute of Sport (AIS): countermovement jump (CMJ); loaded countermovement jump (CMJ+15Kg); and drop jump (DJ). Each jump was performed at the first strength session of the week while on residence in AIS. Improvement across each session was statistically analysed for meaningful changes across the squad mean values (N=12) using confidence interval percentages (CI %) and qualitative assessment. This analysis was performed across power, velocity and height variables for each CMJ (CMJ and CMJ+15Kg) and flight time, contact time, jump height and reactive strength index (RSI) for DJ. Each performance variable selected for analysis improved with the greatest percentage changes coming from peak velocity (m/s) for CMJ of 19.03% (95% CI 0.048 to 0.570 m/s) and CMJ +15Kg of 15.22% (95% CI 0.033 to 0.352 m/s). The second variable to illicit the greatest mean change for both variations of CMJ was mean power (W) with CMJ improving by 16.15% (95% CI 190.4 to 992 W) and CMJ +15Kg by 13.43% (95% CI 170.9 to 715.9 W). 4 week periods of competition did show decrements in all performance variables however across the board these were not shown to be meaningful changes with qualitative values ranging from very unlikely to possibly not. All DJ variables also improved across the testing period with the most meaning changes shown in contact time percentage change of 29.35% (95% CI 0.131 to 0.031 s) and RSI 25.5% (95% CI 0.062 and 0.679). Strength and conditioning training has a positive effect of jump performance variables across a range of jumps. Travel and competition has been shown to decline these improvements, although the decrement has been shown to not be meaningful.

10.3 Appendix 3: Survey of Current practices in long term athlete development of junior athletes in high performance sport

PART A – Professional Background

1. Are you male or female?

   ☐ Male

   ☐ Female

2. *What sport(s) do you currently have professional involvement with?

3. *What level of athlete/player are you currently working with? For example representative level, or age group?

4. What is your title within the organisation you are currently working?

5. What is the name of the organisation you are currently working for?

6. Briefly outline your professional experience? Include what sports you have worked with, for how long, and what level of athlete/player.

PART B – Long Term Athlete Development

Long Term Athlete Development models are very popular within national sporting organisations, in most countries it is mandatory for each sport to have formed their own pathway or model for coaches to work towards. The aim of the following questions is to gain a general understanding of the depth to which elite sport practitioners have awareness of the concepts of LTAD and the alternative models that have been put forward in the literature.

7. *Are you aware of the models below?

	Yes	No
Balyi - Long Term Athlete Development (LTAD) Model		
Côté et al - Developmental Model of Sport Participation (DMSP)		
Lloyd - Youth Physical Development Model (YPD)		

8. Please state any other models you are aware of?

9. Of the models listed previously please provide an indication to your level of understanding for each model?

	in depth understanding	general understanding	vague understanding	no experience of
Balyi - LTAD				
Cote - DMSP				
Lloyd - YPD				

Other (please specify understanding)

10. *Do you use their guiding principles when working with developmental athletes?

☐ Yes

☐ No

11. Can you please give a short description of how you apply these principles?

12. Of your experience in using these principles have you found them effective in developing you athletes?

☐ Not effective

☐ Somewhat effective

☐ Very effective

13. How do you think these models could be improved upon?

PART C – Application in Practice

Commonly the literature relating to athlete development uses markers of growth, maturation or age as reference points from which to plot motor quality and physiological improvements.

The aim of the following questions is to gain an understanding of if you measure growth and maturation, how do you do it? and if you use performance measures with junior athletes what do you use and how are these results interpreted?

14. *When dealing with youth athletes do you measure indicators of growth and maturity and how often?

	Daily	Weekly	Monthly	Quarterly	6-monthly	Yearly	Never
Height	○	○	○	○	○	○	○
Weight	○	○	○	○	○	○	○
X Ray	○	○	○	○	○	○	○
Ultrasound	○	○	○	○	○	○	○
Biochemical Marker	○	○	○	○	○	○	○
Secondary Sexual Characteristics	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Other (please specify)

15. Do you use performance based assessments with junior athletes? If so, how often do you assess?

	Yes/No	Frequency
Maximum Strength		
Aerobic Power		
Anaerobic Power		
Explosive Strength/Power		
Flexibility		
Sport Specific		

Other (please specify)

16. What assessments do you use for these qualities?

Maximum Strength

Aerobic Power

Anaerobic Power

Explosive Strength/Power

Flexibility

Sport Specific

Other

17. Are the performance measures that are used here, used by the coach to determine selection or for any other decisions?

☐ Yes

☐ No

18. Please provide a short explanation of how the performance measures are used?

19. How useful do you feel performance assessments are when dealing with junior athletes?

☐ Useless

☐ Somewhat useful

☐ Very useful

20. Please provide a short explanation of how useful you feel performance measures are?

PART D – Barriers to Implementation

The following questions are used to gain an insight into how elite sport may use long term athlete development concepts in the future and what are the barriers to their implementation at present.

21. If you had the opportunity to change anything to make your athlete development process better, what would you do and how would you do it?

22. At present what are the barriers to you implementing these changes?

PART E – Movement Assessment

It is typical of elite coaches to use some sort of movement assessment criteria to screen for movement ability and dysfunction. The aim of the following questions is to gain an understanding of what elite practitioners are using at present and how they use the information.

23. As part of your coaching program do you use a form of movement assessment?

☐ Yes

☐ No

24. Can you please comment on if you use an assessment tool already available and commercially available or your own version?

25. As part of your screening process do you also include a clinical musculo-skeletal screening performed by a physiotherapist?

☐ Yes

☐ No

26. Can you please list the movements that you use as part of your assessment?

27. *How useful do you feel movement assessments are when dealing with athletes?

☐ Useless

☐ Somewhat useful

☐ Very useful

28. How often do you assess?

☐ Yearly

☐ 6 monthly

☐ 3 monthly

☐ Monthly

☐ Weekly

29. Can you please comment on areas for improvement within your assessment process?

PART F – Future Knowledge

30. Where in your opinion are the gaps in the body of knowledge understanding development of youth athletes?

31. How do you feel this information should be gathered?

32. How should this research then be communicated to reach the targeted audience?

☐ Peer reviewed scientific journal

☐ Peer reviewed coaching journal

☐ Coaching magazine

☐ Conference presentation

☐ Coaching workshop

☐ Other (please specify)

* denotes a question requiring an answer prior to continuing

10.4 Appendix 4 Athletic Ability Assessment - Exercises, rationale and scoring criteria

Exercise	Selection Rationale	Assessment Items	Score		
			3	**2**	**1**
Prone Hold on hands 2 min	Isometric hold linking upper body, trunk and lower body. The ability to maintain neutral alignment throughout body enables the coach to assess scapular positioning under load and hip stability and control under tension. Being able to stabilise and control trunk integrity is a cornerstone to all subsequent actions in sport and movement.	Upper back/ shoulder position	Scapula depression and retraction constant for 2 min No protraction or elevation of scapular	Inconsistent positioning (repositioning) throughout the 2 min	Unable to attain correct position
		Hip position	Neutral hip positioning with no anterior/posterior tilt or rotation	Inconsistent positioning (repositioning) throughout the 2 min	Unable to attain correct position
		Time	> 2 min	1-2 min	< 1 min
Lateral Hold on hands Left and Right Sides 2 min	Lateral stabilisation illustrates ability of lateral structures to control body weight with correct trunk, hip and shoulder position. This is particularly important in sports where the athlete has to control body weight in multiple directions	Upper back/ shoulder position	Scapula depression and retraction constant for 2 min No protraction or elevation of scapular	Inconsistent positioning (repositioning) throughout the 2 min	Unable to attain correct position
		Mid-line alignment	Able to maintain full mid-line alignment with no rotation or side flexion through trunk or hips	Inconsistent positioning (repositioning) throughout the 2 min	Unable to attain correct position
		Time	> 2 min	1-2 mins	< 1 min

Overhead Squat 10kg Olympic Bar x 5 repetitions	Squat movement with overhead position of arms, with load, highlights strength of upper body to hold this position along with compensatory patterns through shoulder/arm/thoracic spine to cope with this position and load whilst also assessing lower body mobility and strength.	Hands/Bar Overhead	Maintains bar overhead with appropriate shoulder/thoracic extension & trunk angle with no rotation	Bar over mid-foot but incorrect movement patterning	Excessive or inappropriate trunk inclination
		Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every rep	Inconsistent form with some perfect reps **OR** minor misalignment on all repetitions	Unable to attain correct position
		Depth	Hip below knee (below parallel) while maintaining neutral spine for all repetitions	Depth beyond parallel for some but not all reps	Not able to achieve required depth for any reps
Single Leg Squat off box Left and Right Sides x 5 repetitions	Single leg ability is critical as a foundation skill for locomotive movements in a majority of sports. SL Squat has the ability to bring to light a range of coordination, proprioceptive, strength and mobility deficiencies in a unilateral environment. The ability to SL squat in a controlled environment indicates movement efficiency to progress training load to include more complex technical abilities.	Trunk angle	Maintains perfect trunk posture for all reps	Inconsistent or uncontrolled forward lean and/or movement from neutral lumbopelvic position	Excessive and uncontrolled forward lean and/or movement from neutral lumbopelvic position
		Hip/Knee/Ankle Alignment	Perfect alignment and control of hip/knee/ankle throughout every repetition	Inconsistent form with some perfect repetitions **OR** minor misalignment on all repetitions	Poor alignment throughout

		Depth	Hip below knee (below parallel) while maintaining neutral spine for all reps	Depth beyond parallel for some but not all reps	Not able to achieve required depth for any reps
Walking Lunge 20kg Olympic Bar x 10 steps	Lunge positions incorporate hip mobility, trunk stability, strength, and motor control in one exercise. The complex interaction of these components illustrates dysfunctional patterns or components of athletic movement.	Knee/Ankle Alignment	Perfect alignment and control of knee/ankle throughout every rep	Inconsistent form with some perfect repetitions **OR** minor misalignment on all repetitions	Poor alignment throughout
		Hip Control	Perfect alignment of hips throughout	Inconsistent form with some perfect reps **OR** minor loss of control on all reps	Excessive loss of control from neutral throughout the movement
		Trunk Control	Maintain neutral spine throughout No forward or side flexion/movement	Inconsistent form with some perfect reps **OR** minor loss of control on all reps	Forced lumbar extension or lack of trunk control during force production
Single Leg Forward Hop Left and Right Sides x 3 repetitions	The capability to reduce and stabilise forces in a unilateral environment is critical for change of direction and multi-sprint ability in many sports and training modalities. Being able to reduce force and stabilise efficiently not only quickens the ability to change direction and therefore increasing sporting performance, but efficiency through this movement is likely to reduce risk of noncontact injury incidence. SL power production is also a key component of acceleration in sport.	Hip/Knee/Ankle Alignment	Perfect alignment of hip/knee/ankle	Inconsistent form with some perfect reps **OR** minor misalignment on all reps	Poor alignment throughout
		Balance/Control	Landing with perfect balance and control	Sticks landing but is unbalanced. Adjustments made via other	No balance/control on landing

				body movements	
		Power Position on Landing*	Lands in Single Leg power position/quarter squat after every rep	Inability to land in power position on some but not all reps **OR** makes adjustments post landing to attain power position	Excessive hip/knee/ankle flexion. Poor positioning to reproduce force.
Lateral Bound Left and Right Sides x 3 repetitions	Lateral bound and stick progresses the SL hop to mimic the forces produced to change direction. Change of direction and rotational forces confound the risk of injury, particularly of non-contact injury and especially in females. For an athlete to perform agility or change of direction drills and sports safely, lateral bound and stick ability has to be correct.	Hip/Knee/Ankle Alignment	Perfect alignment of hip/knee/ankle	Slight deviation from ideal landing alignment	Poor alignment throughout
		Balance/Control	Sticks the landing with perfect balance and control	Sticks landing but is unbalanced. Adjustments made via other body movements	No balance/control on landing
		Power Position on Landing*	Lands in Single Leg power position/quarter squat after every rep	Inability to land in power position on some but not all reps **OR** makes adjustments post- landing to attain power position	Excessive hip/knee/ankle flexion. Poor positioning to reproduce force.

Push ups Minimum repetitions = 20 reps (males), 12 reps (females)	The ability to move and control bodyweight is vital for many sports and training environments. This ability should incorporate correct movement mechanics of the upper body, particularly scapula and trunk position and synchronicity of movement.	Scapulohumeral rhythm	Scapula depression and retraction constant throughout movement No protraction or elevation of scapular or flaring of elbows	Inconsistent form. Some perfect reps.	Poor scapula positioning and control for all reps
		Body Control	Prefect body control and alignment for every repetition	Prefect body control and alignment for some but not all reps	Poor body control and/or alignment for all reps
		Complete repetitions	M ≥ 20 F ≥ 12		M < 20 F < 6
Chin ups Minimum reps = 10 repetitions (males), 4 repetitions (females)	Pulling strength and control is vital for good long term shoulder health and a sound indicator of upper body strength. Chin Ups should highlight gross upper body pulling strength. Chin Ups will also indicate sound scapula rhythm and muscle recruitment patterns in a vertical direction under bodyweight load.	Scapulohumeral rhythm	Scapula depressed and retracted throughout hang. Symmetry of scapulohumeral rhythm during pull and lowering phase of exercise. No scapula elevation or winging.	Inconsistent form. Some perfect repetitions **OR** slight asymmetry	Poor scapula positioning and control for all repetitions
		Body Control	No swinging. Prefect body control for all repetitions	Prefect body control for some but not all repetitions	Poor body control and/or alignment for all repetitions
		Complete repetitions	M ≥ 10 F ≥ 4		M < 10 F < 4

* 'Power' position is defined as the optimal individual body position resulting from appropriate reduction and stabilization of forces through the lower body and is commonly used as a coaching point for landing and jump technique. The additional elements of balance and trunk position are included in this definition to fully assess the body's ability to reduce and stabilise throughout the full kinetic chain. This body position definition is applicable to bilateral and unilateral positions.