

The effects of sprint and bounds training on 0-30 m running speed in elite adolescent rugby league players

Cale Wallace

B.Ed (Social Science)

Master of Philosophy

November 2008

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1968.

Acknowledgement of Authorship

I hereby certify that the work embodied in this Thesis is the result of original research, the greater part of which was completed subsequent to admission to candidature for the degree.

Signature:..... **Date:**.....

Acknowledgements

I would like to thank Dr Robin Callister for her expertise in the areas of sports science and statistical analysis. Your efforts in refining my thesis were outstanding and truly appreciated.

Professor Ronald S. Laura, you are a great friend and mentor and I thank you for your motivation and encouragement throughout the project.

Mum, you were my inspiration for this degree. You helped me persevere when I wanted to give up. Everything seems so easy now.

Rebekah, it's finished. Lets move on to the next chapter. Love Cale.

Table of Contents

Abstract

Introduction.....	i
Methods	i
Results.....	i
Discussion.....	ii
Conclusion	ii

Chapter 1

1.0 Introduction.....	1
1.1 Aims.....	2
1.2 Hypotheses.....	2

Chapter 2

Literature review

2.1 Overview.....	3
2.2 Adolescence	3
2.3 Age and maturation.....	5
2.4 The Bio-cultural matrix – developmental framework	5
2.4.1 Biological characteristics	6
2.4.1.1 Changes in body size and timing of maturational change	7
2.4.1.2 Changes in physiological and cognitive characteristics.....	8
2.4.1.3 Development and exercise training.....	9
2.4.1.4 Maturation and training.....	9
2.4.1.5 Distinguishing the effects of growth and training.....	10
2.4.1.6 Growths spurts and training	10
2.4.1.7 Proposed ‘optimal periods’ for development of speed capacities	11
2.4.1.7.1 Movement coordination	11
2.4.1.7.2 Muscular strength.....	13
2.4.1.7.3 Flexibility and mobility.....	13
2.4.1.7.4 Movement speed	14
2.4.1.7.5 Aerobic capacity	14
2.4.1.7.6 Anaerobic capacity.....	15
2.4.1.7.7 Reaction time	15
2.4.2 Social characteristics.....	15
2.4.2.1 Influence of parents.....	16
2.4.3 Psychological characteristics	16
2.5 Summary	17
2.6 Factors contributing to sprint speed.....	19
2.6.1 Stride frequency	19

2.6.2	Stride length.....	19
2.6.3	Flexibility and mobility.....	20
2.6.4	Coordination	20
2.6.5	Efficiency of movement.....	20
2.6.6	Energy provision for sprinting	21
2.6.6.1	Children are not metabolic specialists	21
2.6.7	Reaction time	22
2.7	100-m sprint and team-sports sprint models.....	23
2.7.1	100-metre sprint model	23
2.7.2	Team-sports sprint model	25
2.8	Contributions to speed - initial movement and acceleration.....	28
2.8.1	Technique.....	28
2.8.1.1	Acceleration technique.....	29
2.8.1.2	How force is applied during acceleration	30
2.8.1.3	Muscle mechanics during acceleration	30
2.8.1.4	Pick up acceleration (PMA).....	31
2.8.1.5	Training for technique.....	31
2.8.1.6	Relevance to adolescents	32
2.8.2	Mobility.....	33
2.8.2.1	Training for mobility.....	33
2.8.2.2	Relevance to adolescents	33
2.8.3	Strength.....	34
2.8.3.1	Maximum strength	34
2.8.3.2	Power performance	35
2.8.3.3	Training for strength and power	36
2.8.3.4	Plyometric training.....	37
2.8.3.5	Bounding as a safe training tool.....	38
2.8.3.6	Training for power	38
2.8.3.7	Relevance to adolescents	39
2.8.4	Coordination – synthesised modes of training.....	40
2.8.4.1	Training for acceleration.....	41
2.8.4.2	Training for maximal velocity	41
2.8.4.3	Relevance to adolescents	43
2.8.5	Turnover.....	43
2.8.5.1	Training for turnover.....	44
2.8.5.2	Relevance to adolescents	44
2.8.6	Muscle endurance	45
2.8.6.1	Training for muscle endurance	45
2.8.6.2	Relevance to adolescents	46
2.8.7	Energy systems	46
2.8.7.1	Relevance to adolescents	46
2.9	Summary	46
2.10	Responses to exercise training in adolescents	47
2.10.1	Distinguishing training effects from those of growth and maturation	48
2.10.2	Training to improve anaerobic performance in children	49
2.10.3	Importance of testing specificity.....	49
2.10.4	Speed training in adolescence	50
2.10.4.1	The impact of development on speed training.....	51
2.10.4.2	Evaluation of the effects of speed training	51
2.10.5	Plyometric training in adolescents	57

2.10.5.1 Plyometric activities.....	57
2.10.5.2 The impact of development on plyometric performance	58
2.10.5.3 Evaluation of the effects of plyometric training	58
2.10.6 Strength training in adolescents	62
2.10.6.1 The impact of development on strength training	63
2.10.6.2 Evaluation of the effects of strength training	63
2.10.6.3 Muscle endurance	64
2.10.7 Aerobic training in children	69
2.10.7.1 Effects of aerobic training in children	69
2.10.7.2 The impact of development on aerobic training	71
2.10.7.3 Selection bias of subjects	72
2.10.7.4 Intensity and specificity of training	73
2.10.7.5 Specific effects of training	74
2.10.7.6 Evaluation of the effects of aerobic exercise	75
2.10.7.7 Limitations of VO ₂ maximum test protocols	76
2.10.8 Energy systems in children	81
2.10.9 Adolescent's capacity to adapt to a training program.....	81
2.10.10 Importance of speed to adolescent sports performance	82
2.11 Summary	83

Chapter 3

Methods

3.1 Study design.....	84
3.2 Subjects	84
3.2.1 Health screening questionnaire	85
3.3 Exercise Testing	85
3.3.1 Warm-up and cool down.....	86
3.3.2 Speed and bounds testing conditions	86
3.3.3 Timing of sprints.....	87
3.3.4 Measurement of bounding distance	87
3.4 Training.....	87
3.4.1 Fitness training.....	90
3.4.2 Speed training	90
3.4.3 Bounds training	90
3.5 Statistical analysis.....	91

Chapter 4

Results

4.1 Participants.....	93
4.2 Attrition.....	93
4.3 Attendance at training	94
4.4 Comparison of groups prior to training	94
4.4.1 Analysis of responses to training of completers	94

Chapter 5

Discussion

5.1 Introduction to discussion	97
5.2 Participants and attrition	97
5.3 Influence of pre-training sprint speed on responses to training	98
5.4 Influence of pre-training bounds performance on responses to training	98
5.5 Training effects on 10 m and 30 m speed	98
5.6 Training effects on bounds performance	100
5.7 Training program-specific effects on sprint speed and bounds performance ..	100
5.7.1 Effects of fitness training on sprint speed	100
5.7.2 Effects of fitness training on bounds performance	101
5.7.3 Effects of sprint training on sprint speed	102
5.7.4 Effects of sprint training on bounds performance	102
5.7.5 Effects of sprint and bounds training on sprint speed	103
5.7.6 Effects of sprint and bounds training on bounds performance	103
5.8 Limitations of the study and recommendations	104
5.8.1 Group stratification prior to group assignment	104
5.9 Future directions	105
5.10 Conclusion	106

Appendix A

Ethics Documents	108
------------------------	-----

Appendix B

Data	119
------------	-----

Bibliography

Tables

Table 2.1 Definitions of terms relating to adolescent development	4
Table 2.2 Interactions of Growth, Maturation, and Development.....	6
Table 2.3 Definition of terms relating to speed and power training.....	18
Table 2.4 Proposed relative importance of maximum leg strength and speed strength qualities for sprint performance	35
Table 2.5 Plyometric training for the lower body.....	39
Table 2.6 Factors affecting the intensity of lower body plyometric drills.....	39
Table 2.7 Lower body plyometric drills	40
Table 2.8 Training variables to improve acceleration and maximal velocity.....	40
Table 2.9 Factors affecting the intensity of short speed drills.....	41
Table 2.10 Speed training studies in boys 10-17 years old.....	54
Table 2.11 Summary of speed trained adolescent athletes compared to other adolescent training groups.....	55
Table 2.12 Summary of plyometric training studies in adolescent boys 10-17 years old.....	60
Table 2.13 Summary of strength training studies with adolescents 10-17 years.....	66
Table 2.14 Summary of training studies on aerobic activity in males 10-17years old.....	77
Table 2.15 Cross-sectional studies reporting aerobic capacity in 10-17 year old males.....	80
Table 3.1 Warm up drills performed at the beginning of each training session	86
Table 3.2 Ballistic stretching performed after the warm up drills	86
Table 3.3 Sprint training program (total volume 3490 metres)	88
Table 3.4 Bounds training program (total volume 450 foot contacts).....	89
Table 3.5 Rugby league fitness program (total volume 45-60 minutes)	89
Table 4.1 Numbers of participants per group across study.....	93
Table 4.2 Comparison of performance results of groups prior to training	94
Table 4.4 Responses to training from completers analysis.....	95
Table 4.5 P-values for responses to training from completers analysis.....	95
Table 4.6 Effect-sizes of responses to training, descriptive categorisation of size of effects of responses to training	96

Figure

Figure 2.1 Framework for sprint performance	44
---	----

Abstract

Introduction

Forty-six elite adolescent male rugby league players (12-17 years) participated in a nine-week study to determine the effects of three exercise training programs on 0-30 metres sprint running time and bounds performance (10 bounds). Subjects were randomly assigned to a rugby league fitness group (F) n=12, a sprint group (S) n= 14 and a sprint-bounds group (SB) n= 20. Forty-two subjects completed the study.

Methods

Separate sessions for fitness, speed, and bounds were conducted once a week for nine weeks. To determine the effect of training a two-way analysis of variance was performed, followed by post-hoc paired t-tests to allow pairwise comparisons when significant interactions were found. Significance was set at $p < 0.05$. Statistical analysis was performed using SPSS for Mac (version 13.1). Effect sizes were calculated to evaluate the meaningfulness of observed changes.

Results

Moderate improvements ($p < 0.05$; 5%) were observed in both the F and SB groups over 10 m. Speed changes over 30 m differed more among the groups. The F group recorded moderate ($p < 0.01$; 4%) improvements, small improvements ($p < 0.01$; 3%) in the SB group and trivial difference ($p < 0.05$) in the S group. The F and S groups improved by approximately 7% ($p < 0.01$) in bounds performance over 10 bounds whereas the SB group improved by approximately 10% ($p < 0.01$) in bounds performance over 10 bounds. Group S had faster sprint times ($p < 0.05$) prior to training compared to groups F and SB.

Discussion

All three programs led to improvements in sprint speed and bounds distance, but the extent of the improvements varied with the specificity of the training program and pre-training performance level. Groups F and SB had 4-5% improvements in sprint speed over 30 m whereas group S showed relatively trivial changes. In all groups, the improvements were greater over 10 m and least over 30 m. Bounds distance improved more than sprint speed, and the greatest improvement was achieved in the SB group compared to the F and S groups.

Conclusion

Rugby league training (game specific drills and extended efforts) coupled with the various components of physical activity can improve speed and power as effectively as specific speed and power training in adolescent boys. Training for acceleration can selectively improve 0-10 m speed more than 0-30 m speed. Sprint and bounds training have been shown to be safe and effective methods to increase speed and power in this group of adolescents.

Chapter 1

1.0 Introduction

Expert coaching and training programs can improve a child's ability to perform in sport and improve global self-concept and self-esteem (Malina et al, 2004; Caruso & Gill, 1992). However, teachers are not often experts at coaching, and time is limited in a school setting. Therefore a safe, effective and easily implementable program to develop speed and power would be an effective teaching tool for school sports.

Much debate surrounds the most effective training methods to improve acceleration and power in adolescent athletes. Speed and power are vital components of many sports and improvements in these areas can significantly improve performance.

Considering a variety of ways exist to train for improvements in speed and power (strength, power, mobility, flexibility, turnover, coordination, muscle endurance and energy systems), a great deal remains to be learnt about how to apply each of these aspects to selectively improve acceleration and power in the adolescent athlete.

Furthermore, this study examined whether training once a week for sprint and bounds training could induce an adequate change in performance amongst the adolescent cohort. Adult team sport athletes would be more likely to undertake sprint and bounds training 2-3 times in total each week. If training once a week is sufficient to induce a change in performance then this is a significant finding.

Adding to the question of how best to train for acceleration, we must consider the limitations of the adolescent athlete (mechanically inefficient, lack of precise coordination, metabolic non-specialists, increased cost of locomotion, smaller limb lengths). Training components of strength and power can improve speed but for

maximum adaptation the athlete must repeat the game specific efforts as demanded by the nature of team sports. Bounding or plyometric training has been described as the best way to improve the strength qualities as they apply to sprint running. This thesis aims to examine the relationship between sprint and bounds training and acceleration in team sports among male adolescent rugby league players.

1.1 Aims

1. To determine whether short sprint training improves 0-10 m and 0-30 m running speed in adolescent rugby league players.
2. To determine whether short sprint training improves 0-10 m and 0-30 m running speed more than rugby league fitness training in adolescent rugby league players.
3. To determine whether the combination of short sprint and bounds training improves 0-10 m and 0-30 m running speed more effectively than short sprint training alone in adolescent rugby league players.

1.2 Hypotheses

1. Short sprint training improves 0-10 m and 0-30 m running speed in adolescent rugby league players.
2. Short sprint training improves 0-10 m and 0-30 m running speed more than rugby league fitness training in adolescent rugby league players.
3. Short sprint training combined with bounds training improves 0-10 m and 0-30 m running speed more than short sprint training alone in adolescent rugby league players.

Chapter 2

Literature review

2.1 Overview

Many factors influence running speed performance. These include genetic characteristics, neural activation of muscle, motor unit characteristics, motor coordination, muscle fibre type, elastic potentiation, connective tissue, flexibility, hormonal factors, nutrition, energy production and training. Improvements through training practices are the major way to improve an athlete's speed (Klissouras, 1971; Mero, 1998). In children and adolescents, stage of maturation is an additional factor that influences current performance and capacity to respond to exercise training (Malina et al, 2004).

First in this chapter, aspects of adolescent development are examined, including the impact of differences in biological, psychological and social variables that underpin exercise performance as well as training capacity and responsiveness in this particular cohort of athlete when compared to adults. A number of definitions of terms relating to child development are provided in Table 2.1. This will be followed by a review of exercise training and training responses in adolescents with a particular focus on sprint-running and plyometric training.

2.2 Adolescence

Adolescence is the period of time from the beginning of puberty to full maturation or adulthood and is characterised by changes in physical, social, emotional and cognitive development. The age range that pertains to adolescence has been identified as 10-18 years of age (Malina et al, 2004) however, ages of 10-19 years in females and 10-22

years in males reflect more appropriate limits for the onset and termination of adolescence (Malina et al, 2004).

Table 2.1 Definitions of terms relating to adolescent development

<p>Adolescence – the World Health Organisation defines the age of adolescence as between 10-18 years.</p> <p>Adulthood - refers to the full maturation of all biological systems; typically represented as 18 years of age and older by law.</p> <p>Childhood - is defined as the period from the first birthday to the beginning of puberty.</p> <p>Chronological age - refers to the number of years and days elapsed since birth.</p> <p>Development - refers to the interrelationship between growth and maturation in relation to the passage of time. The concept of development also includes the social, emotional, intellectual and motor realms of the child.</p> <p>Growth - refers to observable step-by-step change in quantity and, measurable changes in body size, for example height, weight and fat loss.</p> <p>Infancy - refers to the first year of life.</p> <p>Maturation - refers to qualitative system changes, both structural and functional in nature, in the organism's progress towards maturity for example, the change of cartilage to bone in the skeleton. Maturation can be defined as progress towards the complete state of development.</p> <p>Puberty - refers to the somatic and physiological changes in children as the gonads change to the adult state. Puberty is not normally completed until the person is capable of producing a child. In males; pubic hair and genital development.</p> <p>Skeletal age - refers to the maturity of the skeleton determined by the degree of ossification of the bone structure.</p> <p>Trainability - refers to the responsiveness of developing individuals at different stages of growth and maturation to the training stimulus.</p>

Sources: Williams, 2007; Malina & Beunen, 1988; Plowman, 1989; Malina et al, 2004

2.3 Age and maturation

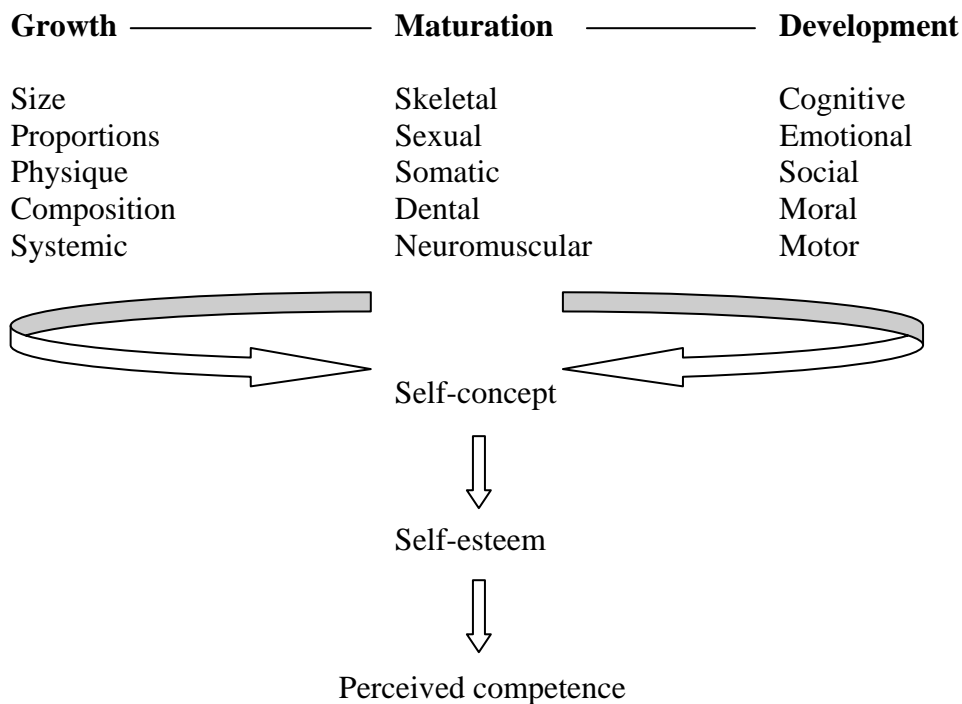
The reference that the general population use to measure or observe growth, development and maturational changes is chronological age (Malina et al, 2004), however, biological development does not always proceed in concert with chronological age (Malina et al, 2004; Williams, 2007). Researchers strive to determine biological age, however public perceptions often classify by chronological age. Some children mature early and others late compared to many of their peers. An adolescent of 13 years of age who matures early can exhibit similar physical characteristics to those of a late maturing 15 year old (Malina 1988; Malina et al, 2004; Williams, 2007). These maturational characteristics can have a significant impact on the sporting success and development of the adolescent athlete (Malina, 1994; Malina et al, 2004). The timing of growth and maturation are primarily genetically determined (Malina, 1994; Malina et al, 2004). Therefore it is genetic factors that are linked to an early performance bias. In some sports such as gymnastics environmental factors such as training and nutrition are also discussed as influencing growth (Malina et al, 2004).

2.4 The Bio-cultural matrix – developmental framework

The impact of growth, development, and maturation on the adolescent athlete in relation to sporting performance occurs in a multidimensional framework known as the bio-cultural matrix (Malina, 1993; Malina et al, 2004). Growth and maturation are biological processes, whereas development is a broader concept that encompasses several behavioural domains (Malina et al, 2004). Table 2.2 highlights factors that according to Malina et al (2004) underpin growth, maturation and development. To better understand a child's bio-cultural matrix we can look at three broad categories of

characteristics: biological, social and psychological (Malina et al, 2004; Malina, 1993). The interplay between the biological, social and psychological factors of the adolescent athlete's sporting environment impacts considerably upon the adolescent and their ability to reach their sporting potential.

Table 2.2 Interactions of Growth, Maturation, and Development



Source: Malina et al, 2004

2.4.1 Biological characteristics

Biological factors that relate to the growth and maturity status of the adolescent athlete play an important role in the adolescent's athletic development (Malina & Bielicki, 1994; Malina et al, 2004). Functionally, adolescence can be viewed in terms of sexual maturity, which begins with the changes in the neuroendocrine system prior to the noticeable overt physical changes, and ends with the complete development of mature reproduction (Malina et al, 2004).

2.4.1.1 Changes in body size and timing of maturational change

Structurally, adolescence begins with acceleration in the rate of growth in stature often termed the ‘adolescent growth spurt’ (Malina et al, 2004). Adolescents who have their growth spurts at younger ages may have greater size and strength as a result, which may lead to superior performance compared to their peers in some sports. This is described as a positive performance bias and is often associated with success in sports such as American football, swimming, track & field, baseball and cycling (Malina, 1988). Sports in which large increases in height and/or weight can be a disadvantage such as gymnastics, distance running, soccer and ice hockey present an exception (Malina, 1988).

As the period of adolescence ends, differences in maturation diminish (Malina, 1988) and the impact of size differences is reduced in many sports. Team sports such as rugby league, rugby union and basketball are exceptions where size differences continue to exert a strong impact on success (Meir et al, 2001; Gabbett, 2006; Baker, 1999). Both rugby codes present a strong bias towards athletes with large size and strength, and basketball discriminates strongly on the basis of height (O’Connor, 1996; Meir et al, 2001; Gabbett, 2006; Baker, 1999; Ostojic et al, 2006; Gillam, 1985; Parr et al, 1978; Viviani & Casagrande, 1990). Once the advantages associated with early growth and maturation are less prevalent, performance bias is linked to the skill and training of the athlete (Malina et al, 2004). However, early maturation may result in greater skill development and access to training or coaching (Malina, 1988; Malina et al, 2004), which may result in more lasting advantages for sports performance.

2.4.1.2 Changes in physiological and cognitive characteristics

Children's developmental characteristics, both morphological and physiological, develop unevenly in a wavelike pattern (Kutsar, 1990). Energy supply and metabolism are activated during intensive growth phases, while body mass increases during slower growth phases (Kutsar, 1990). Preadolescence is characterised by a relatively stable morphological growth pattern, whereas in the adolescence phase, morphological and functional changes are accelerated (Burdukiewicz & Janusz, 1995; Malina et al, 2004; Williams, 2007). Physiological muscle-growth changes with puberty are linked to the increased androgen levels at the time of puberty in young adolescents (Tsolakis et al, 2004; Kutsar, 1990).

The child's level of maturation with respect to neuromuscular and metabolic development can also present advantages and disadvantages to performance (Malina & Bielicki, 1994, Bale et al, 1992). Hakkinen (1989) observed that improvements in motor performance and athletic skill in children are strongly linked to biological maturation. A child who is a late maturer may be at a disadvantage when competing against more biologically mature athletes of the same age (Malina et al, 2004; Williams, 2007, Bale et al, 1992). Furthermore, an early maturing athlete may utilise their early maturation and its associated cognitive advantages such as confidence and motivation, as a 'springboard' for success in their chosen sport (Malina, 1988; Malina et al, 2004). Thus, often this advantage of early maturation is sustained into adulthood.

2.4.1.3 Development and exercise training

The physical development of children with regards to exercise training begins in a play format in childhood and extends to a more structured development towards and during adolescence (Torim, 1988; Mero, 1998). As children's games are often centred around activities such as hopping, stepping and jumping, this suggests that they are already doing high powered muscular work in the developmental stages (Mero, 1998). Basic movement patterns depend upon the rate of neuromuscular maturation, residual effects of prior movement experiences, current movement experiences and growth and maturation (Malina et al, 2004). Therefore when developing speed capacities, these factors will impact significantly on the capacity to respond to training (Malina et al, 2004).

2.4.1.4 Maturation and training

Training influences body composition and performance but whether it affects the rate of maturation is unclear (Malina & Bielicki, 1994; Malina et al, 2004). Malina (1994) suggests that regular physical activity, sport participation or training usually have no effect on the biological maturity of participants in terms of attained stature, the timing of peak height velocity (PHV) and rate of growth in stature. Transient physiological changes do occur with training such as a decrease in body fat (Malina, 1993; Malina, 1988; Malina et al, 2004), and adolescent athletes generally have less body fat when compared with non-athletes (Malina, 1993; Malina et al, 2004). Importantly, Daly et al (2002) reported that training that is too extensive in terms of energy expenditure coupled with inadequate nutrition may compromise growth, particularly in gymnasts.

2.4.1.5 Distinguishing the effects of growth and training

The distinction between the effects of growth, maturation and training on body structure or performance is difficult to determine in the adolescent athlete (Malina et al, 2004). Bone density is one factor that is clearly affected by training (Aldridge, 1993). These effects can be seen in athletes where the dominant limb such as the serving arm in tennis or the kicking leg in football has a higher bone density than the non-dominant limb (Juzwiak et al, 2008; Malina, 1993; Seeman et al, 1996). Strength and power training and, in particular, plyometric or bounding exercises are also believed to enhance bone density at the distal end of the lower limbs (Mero, 1998; Malina et al, 2004). Greater bone density can then increase the adolescent athlete's ability to handle speed-specific training loads (Mero, 1998). Longitudinal studies that account for inter-individual variation may be able to distinguish between the contributions of growth, maturation and training (Malina, 1994; Malina et al, 2004).

2.4.1.6 Growths spurts and training

Growth spurts have been suggested as 'optimal periods' for training to enhance the physical capacity of the adolescent athlete (Ekblom, 1969; Eriksson, 1972; Malina et al, 2004). Whether or not training during this period of rapid growth can potentiate normal athletic development is unclear, although the results of some studies support this hypothesis (Ekblom, 1969; Astrand et al, 1963; Beznak, 1960; Schwartz et al, 1928). Eriksson (1972) and Naughton et al (2000) support the use of high intensity physical training of adolescents if the aim is to develop the adolescent's athletic dimensions. Conversely, a lack of physical stimulation in the adolescent years is believed to adversely affect an athlete's physical capacity (Eriksson, 1972; Naughton et al, 2000; Malina, 2006).

2.4.1.7 Proposed ‘optimal periods’ for development of speed capacities

The concept of ‘optimal or sensitive periods’ for the development of speed capacities has been suggested by many authors (Torim, 1988; Kutsar, 1990; Crasselt et al, 1985; Seagrave 1996; Ondrak & Morgan, 2007; Mero et al, 1988; Eriksson, 1972; Malina, 1988; MacKelvie et al, 2002; Mero, 1998). These proposed ‘optimal periods’ are based upon the individual’s biological, developmental and behavioural readiness (Malina et al, 2004). It has not been clearly demonstrated whether certain training practices can take advantage of this period of physiological change and potentiate normal development. These suggestions are difficult to test and validate given the ethical constraints that surround the adolescent athlete and the limitations such as a lack of longitudinal data, selection bias and the lack of accounting for growth and maturation in the studies carried out. Some support for this concept is provided in the following section reviewing factors contributing to sprint speed performance.

Whilst it can be said that the physical development of sprinters must begin relatively early to avoid missing the optimal age periods for development, it must always be governed by the long-term physical, technical and tactical maturity of the athlete (Kutsar, 1990; Mero, 1998; Dick, 2003). In addition, the approach needs to consider the initial development, consolidation, and progression of speed capacities, as mistakes made in junior athletes may be difficult to compensate for later (Kutsar, 1990; Dick, 2003).

2.4.1.7.1 Movement coordination

Generally, 7-9 year olds can master simple movements with relatively few repetitions whereas more complicated movements do not become permanently fixed until 10-12

years of age (Kutsar, 1990). The nervous system is usually fully developed by 12 years of age (Mero, 1998). Consequently, substantial improvements in coordination of movement are observed in children around this age, and it has been suggested that this is an ideal age to develop stride frequency and the mechanical skills of sprinting (Dick, 2003; Mero, 1998; Singer, 1970; Torim, 1988). Kutsar (1990) identifies coordination as the first of the performance limiting factors to reach a high level. Tittel (1992) reported that biologically younger individuals ~11 years of age showed superior coordination results when compared to biologically older individuals (13 or 14 years of age).

Approximately 11-14 years of age is considered the most favourable period for the development of precise movements with respect to coordination, after which performance coaches can consider the implementation of more complex tasks as they relate to speed capacities (Kutsar, 1990).

It is also important to consider that as growth is providing a constant stimulus for the athlete in the adolescent years it is the role of the coach to attempt to stabilise these growth effects to ensure the athlete's technical model with respect to coordination remains correct (Seagrave, 1996; Vittori, 1996; Kutsar, 1990). The coach must attempt to monitor the adolescent athlete's growth, as the morphological changes that take place need to be accommodated for without the loss of technique. An athlete who cannot accommodate the changes of growth with respect to technique and coordination will most definitely have their progress hindered (Kutsar, 1990; Torim, 1988).

2.4.1.7.2 Muscular strength

Muscular strength development progresses evenly from around the age of 6 years when muscle fibres are believed to begin to thicken, and increase further from around 12 years of age due to the increased synthesis of muscle protein stimulated by androgenic hormones (Kutsar, 1990; Tsolakis et al, 2004). Authors suggest that it is around the age of 15 years when this process begins to stabilise that appropriate strength training should be undertaken (Kutsar, 1990; Malina, 1993; Malina et al, 2004), which could contribute to further increases in muscle mass and strength. However there is scientific data to support the notion of resistance training for preadolescents (Faigenbaum et al, 2005; 2002; 1996; 1993; Ramsay et al, 1990; Pfeiffer & Francis, 1986; Ikai, 1966).

2.4.1.7.3 Flexibility and mobility

The ages of 9-12 years are believed to be an optimal age for flexibility training as it is between these ages that a maximum level of flexibility is reached (Mero, 1998; Sermejev, 1964). Flexibility training is believed to aid recovery and improve the mobility of the athlete and the amplitude of the sprint stride (Mero, 1998). In addition, the power generated by contractile components of the leg muscles increases concomitantly with speed up to 5 m.s^{-1} (Chelly & Denis, 2001), but at speeds greater than 5 m.s^{-1} the elastic components of the muscle provide the additional power for maximal velocity (Chelly & Denis, 2001). Therefore, flexibility and mobility play a vital role in elastic energy recovery and maintaining stride amplitude (Mero, 1998; Chelly & Denis, 2001).

2.4.1.7.4 Movement speed

The optimal period to develop movement speed is believed to be between 7 and 11 years of age (Kutsar, 1990). The introduction of the androgenic around the onset of puberty provides an extra stimulus that can limit the speed of movement in the developing athlete (Kutsar, 1990). It has also been suggested that stride frequency which directly relates to movement speed, should be the first training focus of any speed development program and ideally commence before 12-13 years of age (Torim, 1988; Kutsar, 1990; Mero, 1998).

2.4.1.7.5 Aerobic capacity

Aerobic capacity, which can aid recovery from sprinting, and aids the sprinter performing repeated bouts of intense exercise, as well as the capacity of the aerobic support systems such as the heart, lungs and circulatory system also develops during puberty (Mero, 1998; Mcardle et al, 1991; Callister et al, 1988). Kobayashi et al (1978) in their longitudinal study identified that at approximately 14 years of age, or a year prior to the age of peak height velocity, increases in aerobic power were identified above that attributed to age, growth and maturation. This indicates that the age of peak height velocity is possibly an optimal period with regards to aerobic development in adolescents (Kobayashi et al, 1978). Increases in testosterone one year prior to peak height velocity could be an important factor in both aerobic and anaerobic energy system improvements (Kobayashi et al, 1978; Round et al, 1999; Mcardle et al, 1991). This is described in further detail in section 2.9.7.2.

2.4.1.7.6 Anaerobic capacity

The anaerobic energy systems are particularly underdeveloped until puberty (Malina et al, 2004; Van Praagh, 2000; Van Praagh & Franca, 1998; Bar-Or, 1983; Swei et al, 1998). Anaerobic capacity is determined by muscle quantity (length and cross sectional area), muscle quality (fibre type), energy substrate stores (creatine phosphate and glycogen), anaerobic enzymes (creatine kinase and glycolytic enzymes), and fatigue resistance (acid buffering capacity) (Mero, 1998). Each of these factors develops throughout puberty (Mero, 1998). Thus, puberty is a key period in anaerobic metabolic development (Falgairette et al, 1991).

2.4.1.7.7 Reaction time

A study of 11-15 year olds (athletes/controls) reported that reaction speed improved 4.2% in an athletic group and 4.7% in a control group, with no difference between the groups (Mero, 1998). These data indicate that reaction time can be improved in the adolescent athlete, but differentiating between training effects and inherited genetic characteristics that may affect reaction time is difficult to determine. Reactive capabilities with reference to acoustic, optical and rhythmic capacity, are believed to be fully developed by 12 years of age (Mero, 1998). Therefore, training reactive capabilities to a variety of stimuli as dictated by the nature of the team sport environment as early as possible would be encouraged.

2.4.2 Social characteristics

Sport and physical activity do not occur in a social vacuum and individual athletes do not benefit equally from their biosocial interactions (Malina, 1988; Malina, 1990; Malina et al, 2004). Factors such as economic resources, coaching and adequate

parental support can be crucial elements affecting skill acquisition and motivation, and therefore success (Malina, 1988; Malina et al, 2004). Thus transition from talent identification through to eventual sporting success and mastery is not uniform (Malina, 1988).

2.4.2.1 Influence of parents

The social milieu in which the child is engaged provides varying experiences that can impact positively or negatively on their opportunities and pursuits in relation to their physical and sporting development (Malina, 1988; Malina et al, 2004). One of the most influential of these experiences relates to the parental framework of the child. Supportive parents, who are able to positively deconstruct and appraise performances, can positively influence the child's motivational levels, whereas parents who are apathetic or who place too much pressure on the child or are critical and overbearing can have negative impacts on the child's participation levels (Malina, 1988; Malina et al, 2004; Whitehead, 1993). Therefore, it is not just the child with the greatest ability who will succeed in the sport but the one who can accommodate all the physical, physiological, psychological and emotional demands of their particular sport the best (Malina, 1988; Biddle, 1993; Malina et al, 2004).

2.4.3 Psychological characteristics

There are two important elements of an adolescent's psychological domain that are important: how they perceive themselves (self-concept), and the evaluation of that perception in the context of their interrelationships with others (self-esteem) (Lee, 1993). Self-concept is the organised perceptions that the child makes about their abilities, characteristics and traits and is the framework in which a child interprets

their experiences, structures their behaviour and creates expectations on what is going to happen to them (Lee, 1993; Caruso & Gill, 1992). Self-concept acts as a filter for a desirable self-image, whereas self-esteem is their evaluation of their self-concept within the context of their experiences (Caruso & Gill, 1992; Malina et al, 2004; Malina, 2006).

Interactions between a child's self-concept, self-esteem and their environment play a vital role in the motivation levels of the athlete as children often seek social comparison through sport (Malina, 1988; Malina et al, 2004). Children with low self-concept and low self-esteem may not pursue sports or physical activity even though they may have the physical capacity to excel at these pursuits.

It is believed that at around 12 years of age children develop a mature understanding of the competition process with respect to team dynamics and the interactive and inter-related positions in which they are a part (Lee, 1993). At this stage of developmental progression, children will be able to make more reasonable judgements and perform accordingly in their chosen sport. Approximately 12 years of age is believed to be the time in which specialisation in relation to a particular sport or group of events occurs.

2.5 Summary

Children develop throughout adolescence in accordance with their biological, social and psychological domains. In addition 'optimal periods' for development of the physical capacities can impact upon significantly upon the child's ability to succeed in a particular sport (Malina et al, 2004).

Table 2.3 Definition of terms relating to speed and power training

Acceleration – the movement from inertia to maximal velocity and this usually occurs over a distance of 0-40m in an elite sprinter.

Maximal velocity – the athlete's fastest speed.

Speed endurance – the ability to maintain high levels of speed for extended distances.

Repeat sprint ability – repeated sprint efforts interspersed with short recoveries.

Tempo training – training at a sub-maximal level <85% focussing on technique, rhythm and aerobic exercise.

Stretch shortening cycle – the ability of a muscle to rapidly eccentrically contract followed a concentric muscle action.

Turnover – the combination of stride rate and stride length (amplitude).

Power – refers to the ability to produce force in a given time period, or force times velocity.

Explosive strength – in relation to sprint running it is the strength used to overcome inertia.

Reactive strength – in relation to sprint running it is the reactive strength off the surface as demonstrated in the shorter contacts times as velocity increases.

Maximum rate of force development – utilisation of force as fast and as quickly as possible.

Short range elastic stiffness – ability to use the SSC over a short range.

Fly in sprints – building up to a maximal velocity over a section then holding the maximal velocity.

Wind sprints – sprinting over a set distance then immediately or with minimal recovery, repeating the next sprint over a shorter distance.

Hollow runs – accelerating for a section, holding the speed then increasing the speed for the final section.

Horizontal force production – force produced horizontally to overcome inertia. Also known as rear side dynamics. Knee extension dominates.

Vertical force production – force produced in a vertical direction as the runner increases speed and maximal velocity is reached. Hip extension dominates.

Sources: Francis, 1997; Potach, 2004; Dick, 2003

2.6 Factors contributing to sprint speed

Stride frequency (steps or strides per minute) and stride length (distance covered in a single step or stride) determine an athlete's sprint speed (Winckler, 1991; Seagrave, 1996; Mann, 1985; Kyrolainen et al, 1999; Ross et al, 2001). Stride frequency and stride length operate as a total system and are always interdependent (Mann, 1985; Winckler, 1991). Other factors such as limb length, neural maturation and coordination, muscle mass and strength, flexibility and energy supply influence stride length or frequency and are described below.

2.6.1 Stride frequency

Muscle fibre types and the nervous system influence the speed and coordination of movements and therefore influence stride frequency. Successful sprinters have a high percentage of fast twitch muscle fibres and fast motor units (Mero et al, 1981; Mero, 1985; Ross et al, 2001); these are characteristics that are genetically determined. A high level of coordination is required to capitalize on this genetic material, and maturation of the nervous system as well as exercise training enhances coordination.

2.6.2 Stride length

Limb length exerts a major influence on stride length with longer limbs usually leading to longer stride length. Stride length is not stable until limb growth is complete. Increases in muscle mass and energy production contribute to the maintenance of stride length with multiple strides or repeated sprints (Moravec et al, 1988; Mero et al, 1986).

2.6.3 Flexibility and mobility

Flexibility is defined as the range of movement around a joint whereas mobility is defined as the capacity to perform joint actions through a wide range of movement amplitude (Dick, 2003; ASCA, 2006). Restrictions in flexibility or mobility may compromise stride length and therefore sprint speed. Sports such as sprint running that require fast, powerful movements are at the higher end of the injury risk scale (Mero, 1998). Flexibility is an important factor in preventing injuries and maintaining mobility (Mero, 1998).

2.6.4 Coordination

Coordination is the physical capacity that underpins the mechanical skill or what is often referred to as the technique of sprint running (Dick, 1996; Bennett, 2003; Medicott, 2006). The establishment of a sprint motor unit program is often regarded as the most important training factor when referring to speed development (Mero, 1998). Ballreich (1975) states: 'sprinting for top level sprinters can probably best be improved by developing technical (coordination) skill rather than metabolic conditioning (power) components.'

2.6.5 Efficiency of movement

An inverse relationship exists between maximum speed and the exactitude of movements: the more exact, the less wasted energy and the faster the speed (Saraslanidis, 2000). Therefore improvements in coordination increase efficiency and speed (Saraslanidis, 2000). Young athletes are less economical when compared to more mature athletes. Shorter limb lengths, increased stride frequency but less precise coordination in young athletes are factors that underpin this deficiency (Astrand,

1976). The capacity to provide the increased energy required for movement as a consequence of reduced efficiency is also limited in children and contributes to slower performances (Van Praagh, 2000; Bloxham et al, 2005).

2.6.6 Energy provision for sprinting

Sprinting places large demands on the muscles' capacity to provide large quantities of energy quickly. Of the body's energy systems, sprinting is primarily dependent on anaerobic chemical pathways (Suei et al, 1998) through both the creatine phosphate pathway and glycolysis (Bar-Or, 1983; Malina et al, 2004). The aerobic pathways are important in recovery from sprinting, aid the sprinter performing repeated bouts of sprint activity, and are the major contributors to less intense physical activity.

2.6.6.1 Children are not metabolic specialists

The chemical processes that provide energy are underdeveloped in children compared to adults. Compared to adults, children have a decreased ability to generate mechanical energy from anaerobic chemical sources during short bouts of intense exercise such as sprinting (Suei et al, 1998; Bloxham et al, 2005; Van Praagh & Franca, 1998; Rotstein et al, 1986; Palgi et al, 1984). Successful athletes are often described as being anaerobic (sprinters) or aerobic (endurance athletes) metabolic specialists. Rotstein et al (1986) and Palgi et al (1984) provide strong evidence to suggest that preadolescents and early adolescents are not yet specialised into aerobic or anaerobic types (Bar-Or, 1983; Suei et al, 1998), and development-dependent increases in the capacity to perform both anaerobic and aerobic types of exercise are observed as children grow and mature (Boisseau & Delamarche, 2000).

The lower anaerobic capacity can be observed by the lower lactate production capacity of children during exercise (Zwiren, 1989). Biochemical data such as lower peak levels of acidosis as well as lower activity levels of phosphofructokinase and other glycolytic enzymes support the notion of children's lower anaerobic ability, though these data do not explain the mechanism of such a deficiency (Inbar & Bar-Or, 1983; Zwiren, 1989). In addition, children have been identified as having lower resting concentrations of muscle glycogen, lower rates of anaerobic utilisation of glycogen and higher ventilatory thresholds which can limit the maximum level of acidosis reached, thereby constraining the glycolytic anaerobic system (Zwiren, 1989; Robergs & Roberts, 2000).

As children do not become metabolic specialists until puberty (the fastest child sprinters often also excel at aerobic tasks), any metabolic conditioning to improve anaerobic endurance before this stage will more than likely just be a waste of time for the athlete (Bloxham et al, 2005). Adolescence however may be an ideal time to initiate training to enhance anaerobic capacity. The development of anaerobic endurance allows the athlete to repeat or sustain power and speed efforts (Ross et al, 2001; Callister et al, 1988). Therefore training to repeat fast powerful efforts may be best developed during adolescence with the increased ability to utilise mechanical energy (Suei et al, 1998; Mero, 1998).

2.6.7 Reaction time

In short distance sprint competition, reaction time is an important influence on sprint times. Refer to section 2.7.1 and 2.7.2 for a discussion on the relevance of reaction time in relation to a speed performance.

2.7 100-m sprint and team-sports sprint models

There are two sprint models that must be considered when assessing speed performance as it relates to team sports. Firstly, the 100-m sprint model is based on pure sprinting over a distance of 100 metres and provides a clear account of the different phases of high velocity locomotion that underpin speed performance over such a distance. The 100-m sprint model is concerned with straight line running and focuses on a stereotypical progression through the stages of high velocity locomotion. The second is the team-sports sprint model, which is characterised by repeated sprint efforts over shorter distances taking shorter durations, requiring rapid changes in direction and reactions to more varied stimuli as dictated by the team sport environment. This model is distinctly different to track sprinting (Newman et al, 2004).

2.7.1 100-metre sprint model

A 100-metre sprint performance can be divided into the following phases:

1. Initial Reaction (time from signal or stimulus to first movement)
2. Early Acceleration (acceleration to 10 m)
3. Later Acceleration (acceleration from 10 to 40 m)
4. Maximal Velocity (maximum speed usually between 40-60 m)
5. Speed Endurance (60-100 m) is the capacity to sustain near maximal velocity or minimise deceleration often referred to as 'endurance at speed'.

(Francis, 1997; Seagrave, 1996; Locatelli, 1996; Kukolj et al, 1999; Kotzamanidis, 2006)

Initial reaction and movement time is 'the time it takes to initiate a motor response to a presented stimulus' and the initial force application in overcoming inertia (Dick, 2003; Seagrave, 1996). In 100-m sprint competition the presented stimulus is a starting gun.

Early acceleration is where the athlete is overcoming inertia. Both stride length and stride rate are important but stride length is more important as the athlete uses strength components to overcome inertia in order to produce horizontal force. This is called the phase of great acceleration as the athlete's speed changes quite rapidly as inertia is overcome (Gajer et al, 1999).

Later acceleration is the phase where inertia has been overcome and the athlete's movement shifts from an emphasis horizontal force production to vertical force production. This is also called the phase of minor acceleration (Gajer et al, 1999). The rate of acceleration is lower although the velocity of movement is higher than in the early acceleration phase.

The maximal velocity phase is the next in the sequence. Maximum speed is usually attained between 40-60 m in elite sprinters (Young et al, 2001; Francis, 1997). The emphasis is on vertical force production and the ability to maintain an effective stride rate. The athlete's mechanics change from an emphasis on rear side dynamics with a pronounced forward lean to the more upright position and use of front side dynamics.

The speed endurance phase (60-100 m) is where the athlete aims to maintain his maximum velocity for as long as possible against the onset of fatigue (Ross et al, 2001). The ability to maintain stride length becomes important as the activity of the

neural impulses needed to maintain muscle activation increases and the athlete attempts to decrease the braking force and maximise the propulsive force upon contact.

The value of the 100-m sprint model is that it provides a framework for developing different training components for each of the specific phases. In most team sports, athletes are mainly concerned with distances of 5-10 m (early acceleration) and slightly longer efforts from 20-40 m (Young et al, 2001; Cronin & Sleivert, 2005).

2.7.2 Team-sports sprint model

The team sports model displays a number of variations from the 100-m sprint model, as dictated by the nature of the team sport environment (Young et al, 2002). Firstly, the initial reaction in team sports is not initiated by a starting gun but by a reaction to team signals and on field events (Docherty et al, 1988). Anticipation cues of the team sport environment often reduce the importance that initial reaction has on a 100-m performance (Dick, 1996). Rolling starts are predominant in the team sport environment and this can lead to a shorter acceleration phase (5-10 m) and the ability to attain maximal velocity much faster (Young et al, 2001; Murphy et al, 2003).

Reaction time depends on the speed of neural processing and the development of force to overcome inertia. The distance over which this occurs is approximately one metre. Although a child's rate of neural processing is near adult values by the age of 12, it needs further refinement with respect to the ability to develop force (Mero, 1998). The reaction speed may be fast but the ability to apply force against an external resistance such as a track or playing field may need to develop further.

Secondly, initial acceleration (0-10 m) is of great importance and most speed running in team sports is over this distance (Newman et al, 2004; Baker & Nance, 1999).

Further acceleration (10-40 m) is also important and is affected by rolling starts and anticipation cues (Dick, 1996; Young et al, 2001). The extent of reliance on acceleration depends upon the game and position of the athlete involved (Docherty et al, 1988). In team sports such as rugby league, rugby union, soccer, hockey, basketball and netball, which require a combination of short (5-10 m) and more sustained (20-40 m) efforts, the speed performance is predominately concerned with acceleration (Young et al, 2001; Fitzsimmons et al, 1993; Dawson et al, 1993; Murphy et al, 2003). In rugby league, forwards are generally concerned with initial acceleration (10-15 m) (O'Connor, 1996; Clark, 2006). Outside backs are more likely to accelerate over distances of 10-40 m (O'Connor, 1996; Clark, 2006).

In team sports, where rolling starts and anticipation cues are common, researchers infer that a relatively high proportion of maximum speed would occur over short distances 5-10m and 20-40m (Young et al, 2001; Dick, 2003). In children maximum acceleration usually occurs over distances of between 10-30 metres (Kotzamanidis, 2006).

Thirdly, maximal velocity (maximal speed), which usually occurs between 40-60 m in elite 100-m sprinters, may occur much earlier (20-40 m) in team sport athletes (Young et al, 2001; Cronin & Sleivert, 2005). In team sports the athlete almost never performs a 'pure sprint'. Team sports are characterised by activity of predominately sub-maximal intensity (jogging to get into position, running for a ball at a sub-maximal level) interspersed with high intensity efforts. Recovery may be limited,

therefore the impact of fatigue may limit the athlete's ability to generate maximal velocity.

Finally 30-100 m speed is characterised by elements of speed endurance. In team sports, players rarely have to cover this distance in a single effort. Also, the likelihood that a player will need to cover this distance is position dependent, being more likely to be required of outside backs than forwards in rugby league (O'Connor, 1996). Therefore, this type of speed endurance is emphasised less in training for team sports.

Team sports, which require repeated sprint efforts interspersed with short recoveries over the course of a game, require a special type of speed endurance known as repeat sprint ability (RSA) (Fitzsimmons et al, 1993; Dawson et al, 1993; Bishop & Spencer, 2004; Newman et al, 2004). Therefore in team sports it is not necessarily the fastest athlete in the first sprint who has an advantage, but the athlete who is able to exhibit high levels of RSA throughout the course of the match (Newman et al, 2004). In team sports it is acceleration and the ability to repeat that are the most important speed components (Murphy et al, 2003; Fitzsimmons et al, 1993; Dawson et al, 1993; Bishop & Spencer, 2004; Newman et al, 2004).

Also the need to change direction required of athletes in team sports limits the athlete's ability to attain a true maximal velocity (Baker, 1999). A high proportion of maximal velocity is probably reached much earlier in a team sport environment (20-40 m), however this would not be a 'pure' maximal velocity as it is limited by recovery, smaller distance covered (10-20-m) or (20-40-m) and the shorter duration of the effort 1-7 seconds over a 60-90 min time frame (Dawson et al, 1993; Fitzsimmons

et al, 1993; Bishop & Spencer, 2004). In addition the accelerative and decelerative nature of limbs required for change of direction in team sports and lower centre of gravity (COG) are factors that limit an athlete attaining a true maximal velocity (Cronin & Sleivert, 2005). Finally Kotzamanidis (2006) and Branda et al (1984) identified the distance of 20-30 m in which children will reach maximal velocity. Therefore acceleration in the adolescent athlete may end much earlier than in an adult. In team sports a relative high proportion of maximal velocity is reached over much shorter distances (5-10m) and (20-40m) (Young et al, 2001). Team sports utilise elements of each particular phase of sprint running: reaction and initial movement time, acceleration, maximal velocity and speed endurance.

2.8 Contributions to speed - initial movement and acceleration

Speed is not a one-dimensional capacity but made up of a variety of factors that contribute to varying degrees in any speed performance. These are technique, mobility, strength, power, coordination, turnover (stride rate & stride length), muscle endurance, and energy systems (Mero, 1998). It is important to examine each area and how it contributes to speed development (acceleration) in order to ascertain a standpoint to implement the training strategies that relate to each area.

2.8.1 Technique

Technique refers to the skill or ability to perform a task. The athlete needs to be as technically correct as possible to maximise force production and not waste energy, thus avoiding compensatory features that are difficult to correct in later stages.

Effective sprint technique requires correct coordination and firing patterns from the nervous system, intramuscular and intermuscular systems (Schmidtbleicher, 1992).

Muscle strength is important not only to apply force but also to maintain correct technique (Cronin et al, 2000).

Technical precision with reference to acceleration should be learned and practiced at slower speeds (Dick, 2003). There is an inverse relationship between movement speed and exactitude of movement (Saraslanidis, 2000). Therefore, the technical aspects of sprinting must be mastered before the volume and intensity of the movement can be increased.

2.8.1.1 Acceleration technique

A runner increases speed by increasing stride rate and stride length (Mero et al, 1992; Kyrolainen et al, 1999). Verkoshansky (1996) identifies stride length and not stride rate as having the most impact on acceleration. This is due to the high levels of maximum strength relative to bodyweight and explosive power of the active muscles required in this phase of sprint running to overcome inertia (Young et al, 2001; Verkoshansky, 1996). Stride rate and stride length clearly change with growth and these must be developed within the technical model by sprint runners (Mero, 1998; Mero, 1992). It is the only phase where stride rate and stride length increase concurrently (Verkoshansky, 1996).

Acceleration is best attained by having a low body position, that utilises a triple extension of the ankle, knee and hip joints of the driving leg for take off and high fast pick up of the recovering thigh to overcome inertia (Dick, 2003; Seagrave, 2001; Wieman & Tidow, 1995; Korchemy, 1992; Gambetta, 1996). The amount of inertia is decreased by dorsiflexion of the toe, which also serves to anticipate the great force upon contact (Seagrave, 1996; Korchemy, 1992)

As the support leg (*on the ground*) is driving off the ground in the propulsion phase, the front thigh is blocked (*cannot go any further*) and must move backwards (*recovery phase*) to engage in an alternate leg support phase (Seagrave, 2000; Chu & Korchemny, 1993). The knee remains in front of the foot in the recovery and drive phases and the legs work in a piston type action (Seagrave, 1996; Chu & Korchemny, 1993).

2.8.1.2 How force is applied during acceleration

To gain maximum power in the acceleration phase, and in particular the first few strides, the athlete must execute rear side dynamics, in which the feet strike behind the centre of gravity in a clawing type motion pushing the track back in order to propel the athlete forward and upward (Seagrave, 1996; Young et al, 2001; Saraslanidis, 2000).

Acceleration is a unique phase of sprint performance because of differences of the nervous regulations and muscles involved (move from explosive strength to reactive strength) (Verkoshansky, 1996). However, training for acceleration needs to incorporate the entire spectrum of the phases of speed (reaction and initial movement, acceleration, maximal velocity and speed endurance) to ensure all aspects of the speed capacities are being met (Dick, 1996; Seagrave, 1996).

2.8.1.3 Muscle mechanics during acceleration

In the sprint, muscles have two basic functions; to accelerate forward and to counteract gravity (Wiemann & Tidow, 1995). Both of these tasks can only take place when the athlete has the foot on the ground (Wiemann & Tidow, 1995; Seagrave,

1996). During the acceleration phase it has been suggested that it is mainly the muscles of the knee extensors (quadriceps) that drive the athlete forward (Young et al, 2001; Wiemann & Tidow, 1995; Tupa et al, 1981).

2.8.1.4 Pick up acceleration (PMA)

This stage of acceleration refers to the transition from starting acceleration to maximal velocity running and is usually from 30-60 m in elite 100 m sprinters (Dick, 1987; Gajer et al, 1999). It can be characterised by the subtle changes that occur in the mechanics of the sprint stride, namely where the athlete begins to run more upright and moves from an emphasis on horizontal force production to vertical force production in order to attain maximal velocity (Dick, 1987; Seagrave, 1996). Hip extension as opposed to knee extension begins to dominate. As inertia is overcome the springs become stiffer, metabolic cost is minimised and the athlete makes use of available kinetic energy (Farley et al, 1991).

The athlete aims to limit excessive vertical force and requires the necessary strength components so force can be overcome and applied quickly (Mann, 1985). In team sports due to the limited recovery times and nature of the team sport environment athletes would be unlikely to reach a true maximal velocity.

2.8.1.5 Training for technique

Isolation drills (Table 3.1) and the synthesised performance tasks as described in the section on coordination 2.8.4, are techniques used improve technique for sprinting. When training for technique, tempo runs between 75%-85% of an athlete's best performance are used. This is often described as tempo training, in which the athlete

performs at a submaximal level and concentrates on technique. Drills requiring the athlete to react to a variety of stimuli over 1m, can improve reaction time. Drills requiring the athlete to accelerate overcoming inertia over distances up to 30 m, can improve acceleration. Intensity is moderate and recovery is near full or full. These drills are described in more detail in section 2.8.4. and in the sprint training program (Table 3.3). While drills are extensively used to improve running technique, their efficacy remains unproven in scientific literature.

2.8.1.6 Relevance to adolescents

Children and adolescents display a lack of precise coordination. By focussing on the skill of technique athletes develop a safe and effective platform in which to improve other speed capacities at later stages of development. During acceleration, children who try to run faster without considering the role-played by stride rate and stride length actually increase the negative forces by posterior pelvic tilt (Vonstein, 1996). This is why it is vital to emphasise movement amplitude underpinned by a technically efficient model to ensure children are building an efficient platform for future speed performance (Winckler, 1991).

In children, the distance over which acceleration takes place would be much shorter than adults due to anaerobic limitations, shorter limb lengths, mechanically less efficient, increased oxygen cost of locomotion, lack of precise coordination and decreased strength.

2.8.2 Mobility

Mobility is the capacity to perform joint actions through a wide range of movement (Dick, 2003). A sprinter needs to have enough range of movement to apply and accommodate force and allow the leg a full range of recovery before the next stride (Korchemny, 1992). A sprinter with good mobility is able to maximise the range over which force is applied and sustain efficient leg recovery in anticipation of the next ground strike. Dynamic mobility and flexibility all affect stride rate (Seagrave, 1996). A sprinter that lacks sufficient mobility will limit their ability to utilise the contractive assistance gained as speed increases. During acceleration the mobility of the hips to enhance leg separation and knee lift and the ability to load and unload force on the track in fast transitional steps, is crucial to performance (Korchemny, 1992).

2.8.2.1 Training for mobility

Mobility can be classified into active, passive and kinetic mobility. Active mobility can be trained by a dynamic warm up, which mirrors the range of motion and joint actions in sprint running. Passive mobility requires the athlete to passively stretch the particular muscle groups. Finally kinetic mobility can be trained by performing warm up drills and by sprint running. Mobility drills are explained in more detail in the training program in Tables 3.1 and 3.2.

2.8.2.2 Relevance to adolescents

Adolescents enhance their speed parameters mainly by improvements in stride length in the developmental stages (Mero, 1992). Improvements in mobility allow for the athlete to improve their stride length and movement amplitude during acceleration.

2.8.3 Strength

The strength qualities as they apply to sprint running are relatively independent of each other and are applied in different ratios to each specific part of the speed performance, namely acceleration, maximal velocity and speed endurance (Vittori, 1996; Seagrave, 1996). The most desirable components of strength as they apply to acceleration are maximum strength relative to bodyweight and general speed strength (Young et al, 2001).

2.8.3.1 Maximum strength

By definition maximum strength refers to the ability to exert force with no consideration to velocity of the movement or the ability to sustain it (Young et al, 2001). It is believed that maximum strength is the basic quality that affects power performance as increases in maximum strength almost always lead to increases in relative strength and therefore improving power performance (Schmidtbleicher, 1985). In addition, for athletes that already have a high level of coordination and technique, improvements in strength may improve performance (Almasbakk & Hoff, 1996).

In the acceleration phase of sprint running, in which there is the need to mobilise force and overcome inertia, high levels of maximum strength relative to bodyweight are required (Young et al, 2001; Vittori, 1996; Verkoshansky, 1996). This strength is known as starting strength and is concerned with the initial rate of force development (Cronin et al, 2000). Maximal strength relative to bodyweight, has been shown to correlate highly with initial acceleration to 2.5m or starting strength, whereas absolute strength correlates with maximal speed rather than short speed (Young et al 1995;

Mero et al, 1983). Once inertia is overcome such as the start or early acceleration phases of a sprint, the requirement for maximal strength diminishes and the rate of force development becomes the predominant factor (Schmidtbleicher, 1992).

It must be noted that strength gains alone will not produce an increase in speed without considering the other components that contribute to a speed performance, namely power, mobility, technique, leg turnover rate, stride length and energy systems (Seagrave, 1996). In addition, whilst improvements in an athlete's maximum strength can lead to positive performance gains, improvements in power and speed components are required for maximum adaptation (Stone et al, 2003; Stone et al, 1998). Table 2.4 highlights the importance of strength qualities as they relate to a sprint performance.

Table 2.4 Proposed relative importance of maximum leg strength and speed strength qualities for sprint performance

Strength Quality	Short Sprint (e.g.10m)	Maximum Speed
Maximum Strength Absolute	*	**
Maximum Strength Relative	**	*
General Speed Strength	****	****
Reactive Strength	*	***

**** = very important *** = quite important ** = important * = minor importance (Young et al, 2001)

It can be acknowledged that the relationship between maximal strength and sprinting performance is not totally clear. Research indicates that there is a significant relationship between measures of maximum leg strength and sprinting speed (Young et al, 2001; Cronin & Sleivert, 2005).

2.8.3.2 Power performance

Power refers to the ability of the neuromuscular system to produce force in a given time period, or force times velocity (Schmidtbleicher, 1985; Newton & Kraemer,

1994). Power is the ability to use strength to produce force as quickly as possible, or maximum rate of force development (Cronin et al, 2000). Rapid activation and coordination of the nervous system are both important precursors underpinning power performance (Cronin & Sleivert, 2005). Power is also linked to the velocity of the biochemical responses that regulate the release of energy (Winckler, 1991). Power contributes to a sprint performance by increasing the rate of force development and assisting the athlete in maintaining explosive type actions throughout the course of the sprint (Newton & Kraemer, 1994). As muscles begin to achieve high velocities of shortening, maximal strength has less of an impact (Newton & Kraemer, 1994). In sprinting the short contact times upon ground contact denote that power will be very high (Mero & Komi, 1994). In addition sudden bursts of power are required when rapidly changing direction and accelerating in many sports (Newton & Kraemer, 1994).

2.8.3.3 Training for strength and power

Cronin & Sleivert (2005) identified an individual's best improvements in athletic tasks that involve sprinting, jumping and agility would be best gained by training the athlete with exercises that are closely linked to the dynamics of the activity (Cronin & Sleivert, 2005; Blazevich & Jenkins, 1997). In addition, force relative to bodyweight has been identified as the best predictor of sprint performance over 10 m and 40 m (Cronin & Sleivert, 2005; Baker and Nance, 1999). As the phases of speed require different types of strength training each area of strength can selectively improve each phase of a sprint performance (Young et al, 2001).

An athlete utilises power in different ways throughout the stages of a sprint.

Overcoming inertia in the acceleration stage has a greater reliance upon high force production (explosive strength), whereas high movement velocity is required for maximal velocity (reactive strength) (Cronin et al, 2005; Kristensen et al, 2006).

Researchers advocate using bodyweight for strength training in pre and early adolescence (Giles, 2007). This mode of training seems to be the logical progression from the many-sided activities undertaken during childhood (Mero, 1998). Weight training is believed to be best developed throughout puberty.

2.8.3.4 Plyometric training

Many studies report significant improvements in explosive power using plyometric training in adults (Adams et al, 1987; Blattner & Noble, 1979; Brown et al, 1986; Ford et al, 1983; Polhemus & Burkhardt, 1980; Polhemus et al, 1980; Scoles, 1978); some however, do not (Clutch et al, 1983; Poole & Maneval, 1987; Wilson et al, 1993). In adolescents, all report significant improvements in athletic and non-athletic boys (Table 2.12).

The strength qualities for sprinting are best developed through the use of varied bounding exercises that emphasise strength production at speed (Hakkinen & Keskinen, 1989; Hakkinen et al, 1985; Komi, 1986; Kozlov, 1992; Debnam, 2007).

Training modalities should reflect the dynamic nature of the multi-joint movements in sprint running and the force-time characteristics of the ground contact (Donati, 1996; Mero & Komi, 1994). There is a relationship between maximal bounding and sprint running. Velocity in maximal running is only 14.9% greater than maximal bounding

and 38.9% and 45.8% greater than in max hopping and stepping (Mero & Komi, 1994). This implies that the neuromuscular system may be trained specifically for sprint training by the use of varied bounding exercises (Mero & Komi, 1994).

2.8.3.5 Bounding as a safe training tool

Vittori (1996) identified the use of bounding runs as having great significance in the general preparatory phase of sprinting. In this phase when the athlete is still undergoing elements of base training the bounding runs focus on the speed strength capacity of the athlete, which is closely related to stride length. (Vittori, 1996; Mero & Komi, 1994). In this phase the athlete is not ready to perform the fast runs using the optimal stride length that characterise sprint running and therefore by working on the single component of stride length by bounding, the athlete can progress incrementally and safely towards the next stage of training (Vittori, 1996). Mero & Komi (1994) reported the vertical force in bounds registered 1.64 – 1.93 times greater than running. This finding indicates the need to carefully monitor training loads in relation these high ground reaction forces (Mero & Komi, 1994).

2.8.3.6 Training for power

Plyometric training must focus upon the independent strength qualities maximal strength, explosive strength, reactive strength and strength endurance that are associated with sprint running (Vittori, 1996; Debnam, 2007). Plyometric training is typically performed by bounding across the ground however, depth jumping in which an athlete jumps from a box to mirror the contact times in sprinting, is another common method. Bounding type exercises can be linked to the independent strength qualities as judged by the amount of time the athlete takes in the amortisation phase –

the switch from eccentric to concentric work (Potach, 2004; Chu, 1998). Bounds in which the athlete takes considerably longer to switch from yielding to overcoming phases can be considered strength bounds. Bounds in which the yielding to overcoming phase is fast, are closely related to explosive/reactive type characteristics of sprint running (Chu, 1998). Tables 2.5 and 2.6 identify the training variables that relate to plyometric training and Table 2.7 defines lower body plyometric drills.

Table 2.5 Plyometric training for the lower body

Mode	Lower body plyometrics
Intensity	Near maximal efforts. Intensity can be increased by increasing the height, depth or speed of the movement
Frequency	1-3 sessions a week with a rest period of 48-72 hours
Recovery	A work to rest ratio of between 1:5 and 1:10 between jumps and 3-5 minutes between sets
Volume	Volume is usually judged by distance (not more than 30 metres for bounding across the ground) or foot contacts (no more than 10 foot contacts in a single effort)
Progression	Move from double leg bounds to single leg bounds. Decrease foot contact time and increase the height, depth and speed of movement

Sources: Potach, 2004; Chu, 1998

Bounding with 60-100 foot contacts in the initial phase is recommended. Bounding such as double leg forward leaps, vertical leaps, multidirectional leaps and single leg leaps all utilise the long SSC and can be linked to acceleration.

Table 2.6 Factors affecting the intensity of lower body plyometric drills

Factor	Method to increase plyometric activity
Point of contact	Progress from double leg to single leg support
Speed	Increase the drills speed of movement
Height of drill	Raise the body's COG by increasing height
Participants weight	Add weight

Source: Potach, 2004

2.8.3.7 Relevance to adolescents

Children are already doing high-powered muscular work in the developmental stages.

Bounding is an effective method to improve power and bone density (Mero, 1998).

Therefore bounding is an excellent way of gaining functional strength in the developmental stages.

Table 2.7 Lower body plyometric drills

Type of jump	Definition	Example
Jumps in place	Jumping in the same spot with no rest	Tuck jumps, squat jumps, Borzov jumps – single leg
Standing jumps	Maximum effort vertically or horizontally	Vertical jump or horizontal bound
Multiple hops or jumps	Repeated combination of jumps in or standing jumps	Double leg hop, jumping over barrier
Bounds	Drills that involve exaggerated vertical or horizontal movements	Skips, alternate leg bound
Box drills	Starting on the ground jumping on an off a box	Box jump
Depth jumps	Starting at a higher point and jumping off a box back on to another box	Depth jump

Source: Potach, 2004

2.8.4 Coordination – synthesised modes of training

To improve speed over short distances, movements must be coordinated rapidly at high intensities. Coordination for improvements in acceleration is improved by training acceleration, maximal velocity and RSA. Training variables that relate to short speed (acceleration) and maximal velocity are defined in Tables 2.8 and 2.9.

Table 2.8 Training variables to improve acceleration and maximal velocity

Mode	Maximal or near maximal velocity runs over 30-40 m. Acceleration uses a stationary start and maximal velocity uses a rolling start.
Intensity	95-100%
Frequency	1-3 sessions a week with a rest period of 48-72 hours. CNS must be replenished before the next session.
Recovery	3-5 minutes between reps and between 5-10 minutes between sets. N.B. Full or near maximal recoveries are required to ensure optimal rates of firing.
Volume	Distances and volume vary according to the sport
Progression	Extend distances, decrease rest periods, improve technique, increase speed and the ability to apply force.

Sources: Dick, 2003; Francis, 1997

Table 2.9 Factors affecting the intensity of short speed drills

Factor	Method to increase speed drill intensity
Intensity	Increase speed and execution effort (standing/falling/rolling start)
Distance	Increase the distance
Recovery	Decrease the recovery
Load	Increase the participants load

Sources: Dick, 2003; Potach, 2004

2.8.4.1 Training for acceleration

Acceleration training involves overcoming inertia and progressing rapidly to the point of maximal velocity. The athlete may use various starts of 0-30m at 90-95% to improve this quality. Training for acceleration develops the ability to synthesise the total sprint performance. Gains in acceleration mostly brought about by improvements in stride length development in adolescents (Mero, 1992). Team-sport athletes when training for acceleration should utilise stationary, falling and rolling starts.

2.8.4.2 Training for maximal velocity

Training for maximal velocity can improve acceleration. Improvements in this area are fundamental to sprinting and gains made in maximal velocity will filter down to every other movement skill, such as a fast stride turnover in acceleration necessary to reach a high maximal velocity and improved inter and intramuscular coordination (Seagrave, 1996; Mero & Komi, 1986; Mero et al, 1981; Bosco & Vittori, 1986; Mero & Komi, 1994). Over distances of 10-20 m a high proportion of maximal velocity is reached (Young et al, 2001). Taking into consideration the lack of specificity and the limitations of the adolescent athlete it can safely be assumed that in a 0-30 m acceleration from either a standing or rolling start that a high proportion of maximal velocity will be reached and certainly much earlier than in the adult athlete (Young et al, 2001).

Fly in sprints in which an athlete works up to a maximum velocity and holds it for a short segment or period of time, are the most common training tool for improvements in maximal velocity. These are designed to stress the neuromuscular system to enhance the parameters of maximum velocity (Seagrave, 1996). The athlete builds in to a maximal velocity effort, and effort that would normally be used to focus on acceleration from a standing start, is saved, to be utilised as a fast stride rate in the maximal velocity segment. As the focus is on the neurological system and not metabolic adaptations, the recoveries required before the next repetition should be of maximal duration (Seagrave, 1996).

Improvements in coordination allow for increased stride frequency and relates directly to the nerve-muscle cohesion (Joch, 1990). Relaxation runs where an athlete accelerates for a certain distance (20 m) then holds their form (20 m) before accelerating again are examples of this. Easy tempo efforts of 40-60 m are another method. This type of training improves the athlete's speed as not only does the athlete need to increase the speed of the impulse and mobilise force, but also of the muscles to relax and resynthesise ATP.

The application of this type of training to sports uses is twofold. Firstly, it is thought that the higher an athlete's maximal velocity, the better he/she will be able to perform at a sub-maximal level, and secondly, the technique and mobilisation of energy required for the effort will allow the athlete to improve the efficiency of their energy potential (Verkoshansky, 1996; Seagrave, 1996; Winckler, 1991).

2.8.4.3 Relevance to adolescents

The distances over which an adolescent team sport athlete usually trains are short sprints 10-20 m and longer sprints 20-40 m as represented in team sports time-motion analysis studies (Young et al, 2001). Adolescents also recover faster than adults (Falk & Dotan, 2006, Bloxham et al, 2005). Sufficient recovery is required for gains in the performance of the neuromuscular system (Seagrave, 1996).

2.8.5 Turnover

Stride rate (SR) and stride length (SL) can only be stimulated through the development of coordination and speed, strength, technique, specific endurance, mobility and flexibility (Winckler, 1991). Training must be balanced to improve these functions holistically as it is possible to develop one parameter SR to the detriment of the other (Seagrave, 1996). In sprint running, it is difficult to determine the role played by stride rate and stride length due to the fast speeds in which the athlete executes their running stride (Donati, 1996). The contribution of turnover (stride rate and stride length) is believed to be internally governed and is closely related to muscle fibre type, fast twitch (FT) (Mero et al, 1981). In sprint running the stride length is the predominant variable in overcoming inertia and once the athlete is moving the stride rate becomes more important (Delecluse, 1997; Mero et al, 1981). The framework for sprint performance is presented in Figure 2.1.

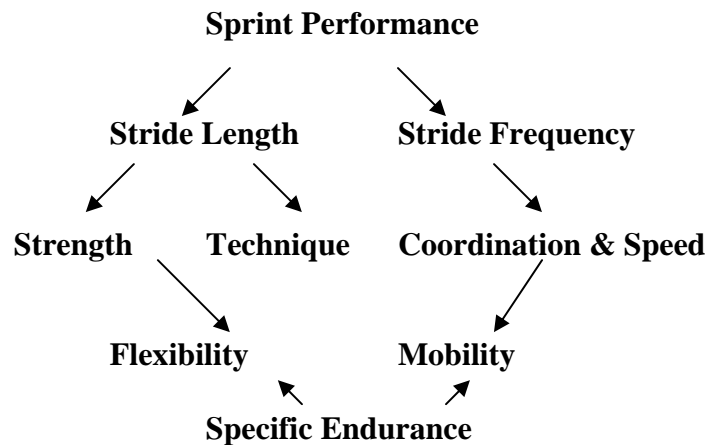


Figure 2.1 Framework for sprint performance
Source: Winckler, 1991

2.8.5.1 Training for turnover

At maximal velocity, both stride frequency and stride length increase then plateau however, stride length levels off before stride frequency (Bosco & Vittori, 1986; Seagrave, 1996; Vittori, 1996; Mero, 1988). We can safely assume that in training for improvements in maximal velocity we must focus on the stride frequency. Moravec et al (1988) identifies maximal running velocity as a pre-condition but not a guarantee for success. Therefore athletes with a higher stride frequency usually have an increased maximal velocity. The higher stride frequency can be utilised by a fast turnover in acceleration. Turnover can be trained by the methods described in the section on coordination or by maximum speed frequency repetitions (Dick, 2003). Furthermore, isolation drills such as elastic band drills, running over speed ladders and small hurdles are other methods.

2.8.5.2 Relevance to adolescents

Importantly it must be said that when training the neurological system the duration of recovery time should be as close to maximum as possible as it is not intended to stress metabolic adaptations (Seagrave, 1996). A point to note is that in junior athletes

where the nervous system is not as developed and is more pliable, less recovery time may be required (Seagrave, 1996; Falk & Dotan, 2006). The considerations for the adolescent athlete with respect to stride frequency are that the training distance must be enough to ensure correct technique at the maximal rate of firing without compromising technique. A distance that is too long will focus on speed endurance based qualities and can adversely affect the technique of the athlete. This would lead to an ineffective stride frequency technique and a less intense firing pattern from the nervous system.

2.8.6 Muscle endurance

Muscle endurance is defined as the ability to perform muscular work against the onset of fatigue (Ross et al, 2001). As the CNS signals begin to fatigue more eccentric work is placed on the muscles as the amortisation phase increases (Ross et al, 2001). Sprint training has been shown to improve muscle endurance and power (Callister et al, 1988). In sprinting and in sport, two mechanical properties of muscle are important: producing force in a short amount of time and the ability to continue to produce force (Newton & Kraemer, 1994).

2.8.6.1 Training for muscle endurance

Training the athlete to hold their maximum speed for longer periods by extending the distances in which they can hold their maximum speed is designed to increase speed endurance or endurance at speed (Francis, 1997). Technique is critical here as poor form leads to inefficient force application. Speed endurance as it relates to acceleration or RSA, can be trained by limiting the rest period between repetitions or increasing the number of repetitions over distances of up to 30 m and 40 m.

2.8.6.2 Relevance to adolescents

Muscle endurance is growth dependent with adolescent athletes only developing this feature when the anaerobic pathways are developed (Suei et al, 1998). Therefore adolescents are limited in their ability to utilise mechanical energy and coaches must be careful not to overload the athlete.

2.8.7 Energy systems

Understanding the bioenergetics of performance allows coaches a greater knowledge concerning the relationship between energy production (fuels) and performance to allow them to better define performance models for sprint running (Vittori, 1996). Section 2.6.6.1 outlines energy systems in children.

2.8.7.1 Relevance to adolescents

As children don't develop adequate anaerobic pathways until well into puberty, repeated acceleration training can become primarily aerobic. To develop the appropriate energy systems coaches must aim to develop the speed capacities, limit the repetitions and stabilise the effects of growth.

2.9 Summary

Coaches cannot simply transplant adult training programs into the adolescent training milieu. Certain general modifications need to be taken into consideration when training children. Children will almost certainly reach their maximum speed earlier and not be able to hold it as long due to limitations regarding the anaerobic energy system, shorter limb lengths, decreased strength and increased oxygen cost of locomotion when compared to adults (Bar-Or, 1986; Seagrave, 1996; Suei et al, 1998)

Children's nervous systems are more pliable than an adults and less recovery time may be required between repetitions (Seagrave, 1996). Secondly, speed endurance or anaerobic endurance is limited by an athlete's ability to generate mechanical energy, and this does not occur adequately until later in puberty (Suei et al, 1998). Therefore, aspects of anaerobic endurance need to be monitored for their relevance in the training program of the adolescent cohort of athlete. Fourthly, the intensity of the training program needs to be carefully monitored for the adolescent athlete so as not as to compromise technique. Finally periods of rapid growth during adolescence may be critical for the coach. The ability to stabilise the athlete technically during these periods is advantageous for the coach and athlete concerned as mistakes made here are difficult to correct later on the training program (Seagrave, 1996; Dick, 2003).

2.10 Responses to exercise training in adolescents

With respect to exercise training and performance, children are not miniature adults. Compared to adults, children exhibit a distinctly lower anaerobic threshold, a lower level of lactate in the working muscle, an increased oxygen cost of locomotion, are mechanically less efficient (lack of precise coordination) and display lower levels of strength and muscle endurance (Astrand, 1976; Rotstein et al, 1986; Suei et al 1998; Sharp, 1999; Bar-Or, 1986; Zwiren, 1989; Mero et al, 1988; Malina et al, 2004; Robergs & Roberts, 2000). Each of these factors impact significantly on how the child accommodates and adapts to a training program in the adolescent stage of development.

When assessing the training effects in children with respect to training there are four key issues that need to be considered; the subject's age and corresponding level of

maturation, the pre study activity level and fitness (selection bias), the intensity and specificity of the training and the specificity of the training effects. Each of the above factors needs to be carefully considered when assessing the effects of training on the adolescent population.

In adolescents, most studies have focussed on aerobic training and the effects of training on peak aerobic power (VO₂ max). Studies on adolescent anaerobic performance have been fewer but have assessed power output, vertical jump, sprint speed and strength. Studies on speed, plyometric and strength training have been more common in recent years. Most though not all studies have shown adolescents to be responsive to training, although considerable variation in responsiveness to training has been observed (Malina et al, 2004).

2.10.1 Distinguishing training effects from those of growth and maturation

Distinguishing the effects of training from those of growth and maturation is a challenge for the researcher (Malina, 1994; Eriksson, 1972; Malina et al, 2004).

Any improvement in performance capacity due to training must be determined to be greater than morphological growth alone would be expected to produce if we are to gauge the adaptations of the particular program (Eriksson, 1972; Naughton et al, 2000; Malina et al, 2004). In research, the change in the exercise training group must be greater than the control to separate training effects from those of normal growth and maturation (Malina, 1994; Eriksson, 1972).

2.10.2 Training to improve anaerobic performance in children

Anaerobic capacity is defined as ‘the energy (ATP) production during exercise that occurs from reactions other than mitochondrial respiration’ (Robergs & Roberts, 2000). Anaerobic exercise is characterised by efforts of high intensity and short duration (Robergs & Roberts, 2000).

There is strong evidence to suggest that the anaerobic performance of children and adolescents is inferior when compared to adults (Inbar & Bar-Or, 1986; Bloxham et al, 2005; Van Praagh, 2000; Malina et al, 2004). Reasons for this include: children are less anaerobic and more aerobic, have less lactate production, lower levels of muscle glycogen, lower rates of glycogen utilisation and a less effective buffering of acid (higher VE threshold) (Almarwaey et al, 2004; Bloxham et al, 2005; Boisseau & Delamarche, 2000; Ferretti et al, 1994; Bar-Or, 1983; Robergs & Roberts, 2000).

2.10.3 Importance of testing specificity

It is important to note the limitations of the test instruments used to assess anaerobic power in children. There are many tests that convey a variety of different information such as the wingate test, margaria step test, vertical jump, counter movement jump, depth jump, and running velocity (Margaria et al, 1966; Cronin & Sleivert, 2005).

Each of the above tests requires a high level of skill with respect to coordination and motor learning, therefore, if the test does not specifically relate to the training program then little or no effect is usually shown. To obtain a reliable result in tests of anaerobic performance there must be a link between training and testing. In relation to sprinting and plyometric training, tests that utilise the stretch shortening cycle and are

assessed relative to bodyweight are believed to be the best predictors of speed and power performance (Cronin & Sleivert, 2005).

2.10.4 Speed training in adolescence

Speed is the ability to move the body as rapidly as possible from one point to another (Potach, 2004; Dick, 2003). Running at maximal velocity over short distances is usually described as sprinting (Nesser et al, 1996; Radford, 1990; Dick, 2003; Mann & Sprague, 1983). Speed training places special demands on the central nervous system in that it requires a fast nerve conduction velocity, a high rate of relaxation, good elastic features of the muscles and the ability to apply force fast against the onset of fatigue (Ross et al, 2001; Mero et al, 1981). During speed training, stretch-shortening cycles (SSC) in the muscle-tendon complex (MTC) are performed in the lower limbs and as the muscles lengthen and shorten these cycles are repeated (Kubo et al, 2000). These cycles take advantage of stored elastic energy in the muscles to produce mechanical energy for improved performance (Cavagna, 1971).

The effects of speed training include improved speed (running velocity), strength and power in the appropriate sprinting musculature (Mero & Komi, 1994; Mero, 1988; Dick, 2003; Callister et al, 1988; Sheally et al, 1992). In addition improvements in the coordination and synchronisation of muscles have been shown to improve from sprint training (Delecluse, 1997; Ross et al, 2001).

Speed as it relates to sprint performance is not one-dimensional, but a composite capacity made up of an initial reaction movement (often described as quickness) and a series of stages of rapid movement (Verkoshansky, 1996; Vittori, 1996; Dick, 2003;

Cronin & Hansen, 2006). These stages were described in more detail in section 2.7.1.

A list of terms relating to sprinting are described in Table 2.3.

2.10.4.1 The impact of development on speed training

Sprint velocity has been shown to increase annually from 5 to 18 years of age in boys (Crasselt et al, 1985; Malina et al, 2004; Mero, 1998). This development appears to occur in two phases. The first phase, around 8 years of age, is believed to be due to developments in the nervous system and increased coordination of the arm and leg muscles (Mero et al, 1988; Mero, 1998; Crasselt et al, 1985). The second phase is said to be between 12 and 15 years of age and is related to the increase in body size, particularly muscle mass and limb lengths, and the corresponding increases in strength, power and endurance that result (Mero et al, 1988; Mero, 1998; Malina et al, 2004; Crasselt et al, 1985). These improvements from 12 years onwards are strongly linked to biological maturation but are influenced by exercise training or other physical activity (Hakinnen, 1989). Growth, maturation and development improve mechanical efficiency in the child as the stride length improves and the athlete makes better use of stride rate and stride length (Astrand, 1976).

2.10.4.2 Evaluation of the effects of speed training

Several publications have emphasised the importance of sprint training and speed development during childhood (Hollman & Hettinger, 1976; Letzelter, 1978; Crasselt et al, 1985; Torim, 1988; Bennett, 2003). However, little information is available regarding the effects of different types of training on various physical performance variables in children and young athletes (Hakkinen et al, 1989).

In the studies conducted on children and adolescents (Tables 2.10 and 2.11), speed training has been shown to improve running velocity, jumping height, power and also contributes to improved neuromuscular and anaerobic performance (Kotzamanidis, 2003; Mero et al, 1988; Mero et al, 1990; Hakkinen et al, 1989; Mero, 1992; Mero, 1993).

In the only longitudinal study to examine the effects of a specific sprint training program on pre-pubertal adolescent boys against a control group, Kotzamanidis (2003) found sprint training to improve running speed over a distance of 30 m and vertical jump. In addition, the sprint training was shown to improve 0-10 m and 10-20 m times but not 20-30 m. From this data we can hypothesise that 20-30 m is the distance over which pre-pubertal boys reach their maximum speed (Kotzamanidis, 2003).

Other studies, in which event specific training was undertaken but not controlled, have investigated the performance capacity in the pre-pubescent and pubescent adolescent athlete (Mero et al, 1988; Mero et al, 1990; Hakkinen et al, 1989). These changes reflected the biological maturation and training of the subjects (Mero et al 1988; Mero et al, 1990). Sprint runners (aged 10.5 ± 0.5 years) were shown to have a higher mean percentage of type II (%) (59.0 ± 8.5), type IIA (%) (36.5 ± 9.2) and type IIB (%) (22.5 ± 9.7) muscle fibres obtained by muscle biopsy, compared to the other athletic groups (weightlifters, tennis players, endurance runners and control group) (Mero et al, 1988). In addition, Mero et al (1991) found the fast group had more than 50% fast twitch fibre when compared to the slow group having more than 50% slow twitch muscle fibres.

Maximal rate of isometric force, rise of the centre of gravity (COG) of a squat and rise of COG in a counter movement jump, dropping height, average force production, vertical jump and running velocity were all higher in the sprint groups in these studies (Mero et al, 1988; Mero et al, 1990; Hakkinen, 1989). Furthermore, changes in anaerobic power were related to serum testosterone concentrations and muscle fibre area (type II). Sprinters and weightlifters performed similarly in powerful movements reflecting a general power adaptation for the age cohort (Hakkinen, 1989).

Mero (1992) found that many-sided physical activities increase relative muscle fibre area and anaerobic work. Mero (1993) investigated jumping, reactive power and sprint speed and the data suggests that the neuromuscular performance improves significantly in males in late puberty. Fournier et al (1982) found an increase in PFK activity in athletes that had undertaken sprint training.

The above findings show that event specific training can improve variables of speed and power in the adolescent athlete. However only Kotzamanidis (2003) utilised a controlled training intervention to achieve their positive result. Sprinters and weightlifters have been shown to have similar force production characteristics in the adolescent cohort (Mero et al, 1990).

Table 2.10 Speed training studies in boys 10-17 years old

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Kotzamanidis, 2003	Untrained	Males sprint group n=15 control group n=15	Sprint group 11.1±0.5 Control group 10.9±0.7	Sprint training (0-30m) twice a week for 10 wks	0-30m sprint	Sprint group 0-10m 2.19±0.15 0-30m 5.45±0.44 Control group 0-10m 2.29±0.15 0-30m 5.74±0.41	2.14±0.12 5.27±0.32 2.30±0.15 5.77±0.43	Yes	Sprint group significantly faster over distances of 0-10m and 0-30m after training

Table 2.11 Summary of speed trained adolescent athletes compared to other adolescent training groups

Key: Sprint speed = SS, Countermovement jump = CMJ, Cycle sprint = CS, Stair sprint = STS, Squat jump = SJ, Speed strength = SPS, Stride length = SL, Running velocity (vertical) = RV, Sprint runners = SR, Endurance runners = ER, Weight lifters = WL, Control group = CG, Athletic group = AG, Tennis players = TP

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Post	Control	Outcome
Mero, 1993	Trained	Males n=29 Female n=29	13.9-15.9	Event specific over 2 years	SS CMJ	CMJ 10.5% SS 3.4%	No	P<0.01 CMJ P<0.05 SS
Mero, 1992	Trained	Males AG n=18 CG n=6	12.6-14.6	Event specific over 2 years	CS	Increase in 15s sprint	Yes	Improved anaerobic performance
Mero et al, 1991	Trained	Males n=16 Fast group n=10 Slow group n=8	11-13	Sprint Weight lifting Tennis	STS CMJ	SR 1.49± 0.10m/s SR 32±5cm	No	Sprint times and CMJ were higher in the sprint group
Mero et al, 1990	Trained	Males athletes ER n=4 WL n=4 SR n=4 CG n=9	10-13 years	SR: 2±1x/wk	CMJ SJ	CMJ SR: 28±3cm CG: 24±3cm SJ SR: 27±3cm CG: 23±3cm	Yes	SR & WL were better than the other groups in terms of force production but not statistically significant
Hakkinen et al, 1989	Trained	Males ER n=4 SR n=4 WL n=10 CG n=6	(SR) 10.5±0.5 (start) 11.5±0.5 (end)	Twice a week according to the basic training principles of the athlete's specific sporting event	CMJ	Sprinters CMJ 31.5cm	Yes	No difference between sprint and strength training

Table 2.11 continued

Key: Sprint speed = SS, Countermovement jump = CMJ, Cycle sprint = CS, Stair sprint = STS, Squat jump = SJ, Speed strength = SPS, Stride length = SL, Running velocity (vertical) = RV, Sprint runners = SR, Endurance runners = ER, Weight lifters = WL, Control group = CG, Athletic group = AG, Tennis players = TP

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Post	Control	Outcome
Mero et al, 1989	Trained	Males SR n=4 ER n=4 CG n=6	11.1-13.1 years	Many sided training up to 8 hours a week	SS SPS SL	SS increased SPS increased 20.3% SL increased 7.6%	Yes	SS increased in the athletic groups in the same manner. SPS increased 20.3% for the athletic group SL increased strongly in the athletic group p<0.05
Mero et al, 1988	Trained	Males TP n=7 WL n=4 ER n=4 SR n=4 CG n=6	AG 11.3±0.9 (start) 10.2±1.4 (end)	AG: Two event specific training sessions per week. Total training consisted of 7hrs per wk (5 sessions) over a one-year period	RV SJ CMJ	SR 1.31±0.11 0.28±0.03 0.28±0.03	Yes	SR performed better in all tests
Fournier et al, 1982	Untrained	Males SR n=6 ER n=6	16-17	SR performed interval runs from 50-250m. Stair running was also performed	Skeletal muscle enzyme changes	SR increased glycolytic capacity	No	Increase in PFK activity and glycolytic capacity in SR

2.10.5 Plyometric training in adolescents

Plyometrics are a type of training that uses the stretch shortening cycle (SSC) to utilise the muscle's ability to produce force at high speeds in dynamic movements (Rimmer & Sleivert, 2000; Lundin & Berg, 1991; Potteiger et al, 1999). These dynamic movements involve a rapid eccentric elongation of the muscle upon ground contact through to a reversal of the movement or an explosive eccentric-concentric contraction (Rimmer & Sleivert, 2000; Lundin & Berg, 1991; Potteiger et al, 1999). The stretch reflex is activated in the muscle by the fast eccentric contraction, which consequently produces a more forceful contraction (Wagner & Kocak, 1997, Potteiger et al, 1999). The muscle is stretched whilst active which results in a greater amount of force production in the contraction phase (Potteiger et al, 1999). Plyometric training capitalises on the increased muscle spindle activity and elastic energy to decrease the amount of time in the amortisation phases – the switch from eccentric to concentric work (Potteiger et al, 1999; Rimmer & Sleivert, 2000). These movements correlate closely to sports actions that require quick movements such as sprinting, jumping and throwing (Lundin & Berg, 1991). In sprint running, the pre-stretch is created naturally by the body's kinetic energy as speed increases (Lundin & Berg, 1991).

2.10.5.1 Plyometric activities

Plyometric exercises include vertical and horizontal jumps in which the athlete aims to jump as high or as far as possible (Rimmer & Sleivert, 2000). It is generally accepted that the more specific the movement to the demands of the sport, the faster the transfer effect. Sprinters who engage in fast powerful movements in a horizontal plane will benefit from bounding across the ground in a series of steps, however, they can also benefit from jumping vertically, thus enhancing components of maximal running velocity (Rimmer & Sleivert, 2000). Athletes involved in team sports such as

rugby league and rugby union can benefit from a mix of the horizontal and vertical plyometric activities (Rimmer & Sleivert, 2000).

As plyometrics focus on fast, reactive type movements, the aim of the training is predominately neuromuscular. Therefore it should be treated as a powerful movement and not a metabolic conditioning tool (Gambetta, 1996). Plyometric training provides the athlete with an excellent stimulus to enhance the inter and intra-muscular coordination at contraction velocities similar to those of team sports such as the rugby codes, soccer, basketball and baseball (Young et al, 1993). (Refer to Tables 2.5; 2.6; 2.7).

2.10.5.2 The impact of development on plyometric performance

Muscle strength is related to muscle cross sectional area and growth and maturation lead to improvements in this area (Hakkinen & Keskinen, 1989). The development of the nervous system and corresponding improvements in motor coordination will almost certainly lead to improved plyometric ability. In mid-late adolescence when the ability to generate mechanical energy through anaerobic sources improves it can be suggested that this would impact significantly on plyometric training responsiveness in the adolescent athlete (Suei et al, 1998).

2.10.5.3 Evaluation of the effects of plyometric training

In the six plyometric training studies (Table 2.12) that have been conducted with adolescent athletes, all have shown improvements in tests of running velocity, squat jump, counter movement jump and a multiple 5 bounds test from plyometric training when compared to controls (Kotzamanidis, 2003; Diallo, 2001; Diallo, 1999; Ingle et

al, 2006; Matavulj et al, 2001; Brown et al, 1986). Four of these studies were conducted on a presumably pre-pubertal population (10-13 years of age) and two studies were conducted on a pubertal population (15-16 years of age) (Brown et al. 1986; Matavulj et al, 2001).

Children are often involved in high intensity games that involve running, jumping and stepping and therefore these activities alone can be enough to improve the speed capacity of the muscles involved (Mero, 1998). Once into puberty, there are even more possibilities to improve speed strength due to the increased hormonal concentrations (Mero, 1998; Van Praagh, 2000). Children can adapt well to plyometric training and further improvements would correspond with nervous system maturation, improved coordination and increases in body size

Table 2.12 Summary of plyometric training studies in adolescent boys 10-17 years old

Key: Sprint speed = SS, Countermovement jump = CMJ, Vertical jump = VJ, Sprint cycle =SC, Squat jump = SJ, Multiple 5 bounds test = MB5, Cycling force velocity test = FV, Drop jump = DJ, Sprint group = SG, Experimental group = EG, Control group = CG

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Kotzamanidis, 2006	Untrained	Males EG n=15 CG n=15	EG 11.1±0.5 CG 10.9±0.7	Plyometric training biweekly for 10 weeks	SS & SJ	Speed test (secs) EG 0-10m 2.24±0.10 0-30m 5.55±0.33 CG 0-10m 2.29±0.15 0-30m 5.74±0.1 Squat Jump (cm) EG 22.99±4.49 CG 21.84±5.26	EG 2.19±0.08 5.41±0.60 CG 2.30±0.14 5.77±0.30 EG 30.96±4.13 CG 21.22±5.51	Yes	EG significantly different (p<0.05) in all speed tests. The EG increased significantly in the SJ after the training program (p<0.01) and had better performance than the CG (p<0.05)
Ingle et al, 2006	Untrained	Males n=54 EG n=33 CG n=21	12.3±0.3	3x/wk for 12 wks Complex training Resistance training and plyometrics	VJ & SLJ	EG VJ 32.6±5.8cm SLJ 1.90±0.22cm CG VJ32.8±4.2cm SLJ 1.92±0.15	EG 33.9±5.9cm 1.93±0.23cm CG 33.1±4.0cm 1.93±0.15cm	Yes	VJ increased significantly in the EG (p<0.01)
Matavulj et al, 2001	Trained	Male n=33	EG Group 1 (50cm DJ) n=11 EG Group 2 (100cm DJ) n=11 CG n=11	Plyometric training 3x/wk for 6 weeks	CMJ	CMJ G1 EG50cm EG 100cm	CMJ G1 EG50 4.8cm increase EG100 5.6cm increase CG no change	Yes	P<0.05 for both EG

Table 2.12 continued

Key: Sprint speed = SS, Countermovement jump = CMJ, Vertical jump = VJ, Sprint cycle =SC, Squat jump = SJ, Multiple 5 bounds test = MB5, Cycling force velocity test = FV, Drop jump = DJ, Sprint group = SG, Experimental group = EG, Control group = CG

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Diallo et al, 2001	Untrained	Males n=20	EG n=10 CG n=10	3 x/wk for 10 wks Plyometrics and circuit training	SC, CMJ, SJ & MB5	EG CMJ 29.2+3.9cm SJ 27.3+4.0cm MB5 10.5+0.7	EG 32.6±3.4cm (p<0.01) 29.3±3.3cm (p<0.05) 11.1±0.8m (p<0.01)	Yes	CMJ and SJ increased significantly 12% 7.3% respectively in the EG
Diallo et al, supp 1999	Untrained	Male n=30	EG n=10 SG n=10 CG n=10	3x/wk for 10 wks EG performed plyometrics SG performed multiple sprints on a cycle ergometer	FV, SJ, CMJ, DJ & SS	N/A	N/A	Yes	EG and SG increased significantly (p<0.01) and (p<0.05) respectively their sprint cycling performance. EG and SG increased CMJ significantly (p<0.05)
Brown et al, 1986	Trained	Male n=26	15±0.7 yrs	3 sets of 10 depth jumps 3 x/wk for 12 wks	VJ (a) with arm swing VJ (b) without arm swing	EG (a) 59±5.0 EG (b) 49.4±2.9 CG (a) 60.4±6.1 CG (b) 51.9±3.9	EG (a)66.3±5.8 EG (b)54.9±5.6 CG (a)64.1±4.8 CG (b)54.7±4.6	Yes	EG improved VJ significantly (p<0.05) with arm swing

2.10.6 Strength training in adolescents

Strength refers to the ability to express force or tension against an external resistance at a specified velocity (Malina et al, 2004; Harris et al, 2007; Newton & Kraemer, 1994). It is an essential component of motor performance, as each specific task requires a certain amount of strength to complete the task (Malina et al, 2004). There are three main areas of strength with respect to sporting performance: maximum strength, elastic strength and strength endurance (Dick, 2003). Most sports require a combination of all three areas of strength (Newman et al, 2004). Strength as it relates to most sports is the capability of the muscle to exert force or torque from the fastest eccentric to the fastest concentric (Newman et al, 2004; Newton & Kraemer, 1994). Strength is related to size, cross sectional area and sexual maturation (Borms, 1986; Malina et al, 2004; Tsolakis et al, 2004). Strength or resistance training requires the athlete to utilise weights or some other form of resistance to improve their athletic strength (Newman et al, 2004).

In the literature on strength training (Table 2.13) in pre-pubertal and pubertal boys, significant gains have been shown with carefully supervised resistance training programs (Malina et al, 2004). These gains are predominately neural with relatively little increase in hypertrophy, which emphasises the role that the nervous system plays in the increases in strength brought about by a resistance-training program (Malina et al, 2004; Borms, 1986). It is not until puberty that hypertrophic results are identified, and correspond with the increase in androgenic hormones that develop during puberty (Malina et al, 2004).

2.10.6.1 The impact of development on strength training

The impact of development on strength is twofold. Firstly children refine motor patterns and learn new skills as they grow and mature and these improvements can lead to positive strength gains (Malina et al, 2004). Secondly, in the pubertal population the increase in hormones and corresponding increase in muscle cross-sectional area can give a performance bias to the stronger athlete (Malina et al, 2004).

Late adolescence is the time when nerve regulations reach maturity, and it is generally accepted that further strength development takes place through hypertrophy (Kutsar, 1990; Hakkinen et al, 1989). In terms of power, which is defined as force times velocity, similarly the gains relate to neuromuscular force production characteristics and motor skill variables (Harris et al, 2007; Newton & Kraemer, 1994). This leads us to believe that tests of explosive strength that require jumping and throwing, are governed by coordination factors which along with force production, combine to determine result of the test (Malina et al, 2004; Dick, 2003). In a strength performance the neurological adaptation develops first, however it can be reasoned that in the adolescent athlete, hypertrophy takes time and may be limited initially by a lack of hormones (Almarwaey et al, 2004; Van Praagh, 2000)

2.10.6.2 Evaluation of the effects of strength training

Training two or three times a week have shown significant improvements in the adolescent athlete. Faigenbaum et al (1993) found that whilst strength may improve it did not have an impact on improved motor performance. This could be linked to the neurological efficiency required of performance tasks and testing specificity.

Furthermore, improvements in various sports activities by the subjects have been

noted from strength training (Faigenbaum et al, 1993). It is important to note the research of Christou et al (2006) in which soccer training alone improved lower limb strength more than that allowed for growth and maturation. This study supports the notion that children become stronger from a variety of athletic pursuits other than specific strength training in their developmental years.

2.10.6.3 Muscle endurance

Literature on training in adolescents, and its effect on muscle endurance, is limited. It is known however that muscle endurance is limited by one's ability to generate mechanical energy through metabolic processes (Suei et al, 1988; Van Praagh, 2000; Bloxham et al, 2005). We can safely hypothesise that muscle endurance and its development occurs more in late adolescence when the anaerobic pathways are adequately developed (Suei et al, 1988). Faigenbaum et al (2005) in the first study to examine the efficacy of 15-20 repetition maximum (RM) training in children on low repetitions (6-10) or high repetitions (15-20) found that only the high repetition group made significantly greater gains (42%) than the control group (4%) in tests of local muscular endurance on a leg press (15 RM), identifying that muscular endurance can be trained in the adolescent cohort and is linked to the specificity of the task and training program.

Ikai (1964) suggests that children adapt to differential responses of strength and endurance depending on age or growth and development. In this study on 8-14 year old boys, younger boys made greater relative gains in maximum strength. In contrast older boys made greater relative gains in muscular endurance from the same training

program. These results suggest different responses to training dependent upon age or more likely growth and development (Ikai, 1964).

Table 2.13 Summary of strength training studies with adolescents 10-17 years

Key: Countermovement jump = CMJ, Vertical jump = VJ, Sprint cycle =SC, Squat jump = SJ, Strength training group = STG, Combination group = Com, Control group = CG, High velocity low resistance = HVLR, Low velocity high resistance = LVHR, Repetition maximum = RM

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Christou et al, 2006	Trained	Males n=26	12-15 STG soccer n=9 Soccer n=9 CG n=8	Resistance training 55-80% of 1RM 2x/wk for 16 weeks	SJ & CMJ	STG SJ (cm) 24.9±1.4 CG 25±2 CMJ (cm) 29±1.6 CG 29±2	STG SJ (cm) 32.4±1.6 CG 27±2.1 CMJ (cm) 35.7±1.4 CG 31.2±1.5	Yes	SJ, leg press and CMJ were all (p<0.05) in the STG. Effect size: 1.65 SJ 1.49 CMJ
##Ingle et al, 2006	Untrained	Male n=54	12.3±0.3 years STG n= 33 CG n=21	Plyometric and resistance training 3 x/wk for 12 weeks	VJ & SLJ	STG VJ (cm) 32.6±5.8 CG VJ 32.8±4.2 STG SLJ (m) 1.90±0.22 CG 1.92±0.15	STG VJ (cm) 33.9±5.9 CG VJ 33.1±4 STG SLJ (m) 1.93±0.23 CG 1.93±0.15	Yes	Increases in VJ & SLJ.VJ (p<0.01)
#Faigenbaum et al, 2005	Untrained	Males n=23 Female n=20	8-12.3 years CG n=12 (10.9±0.9) Low RM n=12 (10.4±1.2) High RM n=19 (10.4±1.5)	Resistance training low RM: 6-10 reps high RM: 15-20 reps Biweekly over 8 weeks	VJ	Low RM (cm) 24.3±4.9 High RM (cm) 23.1±4.7 CG 27.6±6.2	Low RM (cm) 25.1±5.3 High RM (cm) 23.1±4.2 CG 24.2±6.6	Yes	Low RM 3.3% increase in VJ
Kotzamanidis et al, 2005	Trained	Males n=35	CG n=12 Com n=12 STG n=11	Resistance training and resistance and speed training (combined) 3x/wk for 13 weeks	SJ CMJ 0-30m SS	SJ (cm) Com 25.51±2.51 STG 25.71±3.14 CG 25.80±2.46 CMJ (cm) Com 27.83±2.80 STG 27.24±3.41 CG 28.32±2.79 0-30m sprint (secs) Com 4.34±0.17 STG 4.33±0.17 CG 4.50±0.21	SJ (cm) Com 27.50±3.36 STG 26.19±3.45 CG 26.06±2.56 CMJ (cm) Com 29.69±3.55 STG 27.48±3.33 CG 28.26±2.83 0-30m sprint (secs) Com 4.19±0.14 STG 4.31±0.16 CG 4.48±0.20	Yes	Significant differences from pretest (p<0.01) in combined resistance and sprint training group (com) only for SJ and 0-30m speed

First study on complex training in adolescents # First study on 15-20 RM muscle endurance in adolescents

Table 2.13 continued

Key: Countermovement jump = CMJ, Vertical jump = VJ, Sprint cycle =SC, Squat jump = SJ, Strength training group = STG, Combination group = Com, Control group = CG, High velocity low resistance = HVLR, Low velocity high resistance = LVHR, Repetition maximum = RM

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Tsolakis et al, 2004	Untrained	Males n=19	11-13 STG n=9 CG n=10	STG 3x/wk for 2 months Control 6 exercises 3x10 reps	Isometric strength	STG 85.11±8.26 (kg) CG 83.06±6.95 (kg)	STG 100.16±8.39 (kg) CG 83.94±7.13 (kg)	Yes	17.5% increase in isometric strength for the STG, p<0.001. No significant gains by the CG
Faigenbaum et al, 2002	Untrained	Males n=34 Female n=21	CG n=13 Mean age 9.3±1.5 1 Day training 10.2±1.4 2 Day training 9.7±1.4	Once or twice a week for 8 weeks 12 exercises 10-15 reps	VJ	VJ (cm) 1 Day 23.7±5.8 2 Day 22.8±3.9 CG 21.6±2.5	VJ (CM) 1 Day 24.9±6.7 2 Day 24.9±4.5 CG 22.3±2.2	Yes	Both groups increases in VJ
Hetzler et al, 1997	Trained	Males n=30	13.6±0.9 Experienced n=10 Novice n=10 CG n=10	Resistance training 12 weeks 3x/wk	VJ	VJ (cm) Exp 47 Novice 47 CG 41.7	VJ (CM) Exp 48.5 Novice 51.1 CG 41.7	Yes	Increase in VJ after strength training
Faigenbaum et al, 1996	Untrained	STG Males n=11 Female n=4 CG Males n=3 Females n=6	7-12 years STG group mean age (10.8±0.4) CG mean age (10.0±0.4)	Resistance training Biweekly for 8 weeks 2x6 reps on 5 exercises first 4 wks 3x6 reps on 5 exercises last 4 wks	VJ	VJ (cm) STG 23.5±1.4 CG 24.6±1.3	VJ (cm) STG 24.9±1.5 CG 25.1±1.5	Yes	Increase in VJ in both groups
Faigenbaum et al, 1993	Untrained	Male & Female n=23	10.8 (mean age) STG n=14 CG n=9	Resistance training Biweekly for 8 weeks 3 sets of 10-15 reps on 50-100% 1RM	VJ	VJ (cm) STG 22.81±4.14 CG 19.33±6.43	VJ (cm) STG 25.95±5.64 CG 20.82±5.14	Yes	Significant increases in VJ 7% (p<0.05) for STG

Table 2.13 continued

Key: Countermovement jump = CMJ, Vertical jump = VJ, Sprint cycle =SC, Squat jump = SJ, Strength training group = STG, Combination group = Com, Control group = CG, High velocity low resistance = HVLR, Low velocity high resistance = LVHR, Repetition maximum = RM

Study	Subjects	Gender/n	Age (years)	Training	Test variables	Pre	Post	Control	Outcome
Ramsay et al, 1990	Untrained	Males n=26	9-11 STG n=13 CG n=13	Circuit training 3x/wk for 20weeks	Leg press	Leg press (kg) STG ~93 CG ~97	Leg press (kg) STG ~ 112 CG ~ 101	Yes	Leg press 22.1% increase p<0.01
Docherty et al, 1987	Untrained	Males n=34	11-13	Isokinetic circuit training 3x/wk for 4 weeks	SC	15s cycle sprint (w) HVLR330±82.7 LVHR339±82.3 Con 342±65.5	15s cycle sprint (w) HVLR386.9±63.2 LVHR337.8±100.9 Con 363.2±66.1	Yes	Anaerobic power improvements
Pfeiffer & Francis, 1986	Untrained	Males n=80	8-21 Group 1 Prepubescent STG (10.26±1.17) Group 2 Pubescent STG (13.05±0.97) Postpubescent STG (19.75±1.18)	Resistance training 3 x/wk for 9 wks	Isokinetic strength		Knee extension 30 degrees/sec STG +1.2% CG -10.7% Knee extension 120 degrees/sec STG +10.8% CG 0.0%	Yes	Significant improvements in STG p<0.01
Ikai, 1966	Trained	Males	8-14	Strength and endurance 6 days a week for 5 weeks	Upper body ergometer		Maximal strength 10yrs -29.6% imp 12yrs - 23.3% imp 14 yrs - 6.5% Muscular Endurance 10yrs - 45.6% imp 12yrs - 44.8% imp 14yrs - 60.0% imp	Yes	The younger boys made greater relative strength gain and the older boys made greater relative gains in muscle endurance to the same training

2.10.7 Aerobic training in children

Aerobic fitness is defined as ‘the maximal capacity to take in, transport, and utilise oxygen’ (Sharkey, 1997). Increased aerobic capacity enhances the athlete’s ability to perform and recover from repeated bouts of exercise (Callister et al, 1988). Exercise capacity and maximal oxygen uptake VO_2 max increase throughout childhood and adolescence because of improvements in oxygen transport and metabolic capabilities (Robergs & Roberts, 2000). The ability of a child to respond to an aerobic training program depends largely on the child’s initial fitness or activity level, genetics and the training program itself (Eriksson, 1972; Saltin, 1969; Rowell, 1986). If a child has a low fitness level their response to a general aerobic training program will almost definitely be positive (Saltin, 1969; Eriksson, 1972; Rowell, 1986). However, if a child displays a higher fitness level, their response to an aerobic training program will depend largely on the physical development of the athlete and the specificity of the training program (interval or steady state) (Malina et al, 2004). Even taking into consideration stages of development and the specificity of the training program, the adaptations may still be limited in the adolescent athlete (Krahenbaul, 1985).

With respect to aerobic training there are sufficient data to assess effectively the subjects age and corresponding level of maturation (impact of development), the pre study activity level and fitness (selection bias), the intensity (interval or steady state) and the specificity of the training effects.

2.10.7.1 Effects of aerobic training in children

Rotstein et al (1986) highlight the controversy that surrounds aerobic training in children. While some studies (Bar-Or et al, 1980; Lussier & Buskirk, 1977; Smit et al,

1979; Vaccaro & Clarke, 1978) have yielded a positive relationship with regards to aerobic training and its effect on children, other studies (Bar-Or & Zwiren, 1973; Daniels & Oldridge, 1971; Mocellin & Wasmund, 1973; Yoshida et al, 1980) have found no increase in maximal oxygen uptake when children were given a training program that was effective amongst adults.

Children under ten years of age show relatively small (<5%) increases in maximal aerobic power, and it is not until the age of eleven years that an endurance training regime can be said to positively influence aerobic capacity (Malina, 1993).

Schmucker & Hollmann (1974) support this conclusion with their study on well-trained young athletes who showed no statistically significant results from their endurance-training program until they reached 11 years of age. LeMura et al (1999) in their meta-analytic review reported that children in the 8-10 year old age were trainable (ES = 0.47 ± 0.4) but not to the degree of the 11-13 year old age group (ES = 1.1 ± 0.7 , $p < 0.02$). Kobayashi (1978) and Mirwald (1981) found in longitudinal data that VO_2 max wasn't significantly affected until 12 years of age. However, Weber et al (1976) recorded a 10-15% improvement in their prepubescent population of identical twins, with one acting as a control, supporting Brown et al (1972) and Gatch & Byrd (1979) that the preadolescent population can be as trainable as the adolescent cohort. Pate & Ward (1996) in their review of studies that utilised control groups, had physiological measures of training outcomes and clear descriptions of training protocols, found on average a 10% improvement in VO_2 peak amongst children and adolescents.

Young trainees in various sports making the transition into adolescence, approximately 10 years onwards up until the age of 21, show variable gains in aerobic power that are greater than those in children of preadolescent age. These findings suggest an increase in the trainability of the heart and circulatory system around the period of puberty in males (Mero et al, 1988; Malina, 1996).

2.10.7.2 The impact of development on aerobic training

Maximal oxygen uptake is related to the maturity of the athlete (Robergs & Roberts, 2000). Lean body mass, height and weight are the predominant developmental factors that influence maximal oxygen uptake (Robergs & Roberts, 2000). Exercise capacity and maximal oxygen uptake increase throughout childhood (Robergs & Roberts, 2000).

The “trigger hypothesis”, which proposes improvements in aerobic trainability associated with the developmental pubertal changes that occur following puberty, has been described as a major factor in VO₂ max improvements (Naughton et al, 2000; Rowland, 1997; LeMura, 1999). The ‘trigger hypothesis suggests that improvements in the neuromuscular system, various hormone concentrations, an increase in lean muscle tissue, higher oxidative capacity and larger cardiac output, are all factors which can impact upon the metabolic adaptations of the adolescent (LeMura, 1999; Rowland, 1997; Naughton et al, 2000).

In a study by Kobayashi et al (1978) researchers identified exponential increases in VO₂ peak at the peak height velocity (PHV) in well-trained adolescent distance runners (Kobayashi, 1978). In addition, Round et al (1999) reported circulating

testosterone levels rising 1 year prior to PHV, highlighting the sensitivity of this period of development on aerobic trainability in adolescents (Van Praagh, 2000)

Beneke et al (1996) suggested that it may be neuromuscular factors that contribute more than oxidative metabolism and glycolysis to improve aerobic performance in the adolescent cohort (Beneke et al, 1996). Factors such as improved strength, muscle size and improved coordination all improve aerobic performance in children and adolescents.

In the adolescent population (10-17 years) researchers have been limited in distinguishing between the effects of training to that of the child's natural growth and maturation relative to age. In the studies reported most are cross-sectional and therefore factors of growth and development are not considered (LeMura et al, 1999; Krahenbuhl, 1985). Longitudinal data are preferred when attempting to separate the effects of a training intervention with the contribution of growth and maturation with respect to aerobic power (LeMura et al, 1999; Kobayashi, 1978). Aside from the influence of training, hereditary plays a major role in VO₂ max development (Borms, 1986). Physical training interventions may reduce the level that hereditary plays (Klissouras, 1971).

2.10.7.3 Selection bias of subjects

An underlying reason for the disparity in these studies may be selection bias of the subjects. As previously mentioned, children whose initial fitness level is low may have a greater capacity to adapt when compared with children of a higher pre study fitness level (Eriksson, 1972; Saltin, 1969). The degree of VO₂ max increase is

inversely related to the initial level prior to training (Plank et al, 2005). Therefore a child with a low VO₂ max may improve greatly and vice versa (Plank et al, 2005) Furthermore, the researcher needs to interpret improvements in relation to the training background (athletes/non-athletes, physical training/physical activity) as well as for growth and maturation (Naughton et al, 2000). Many children are more active than adults, and a more intensive aerobic training program may be needed to elicit a response (Rotstein et al, 1986; Eriksson, 1972; Trudeau & Shephard, 2005; Rowland, 1997).

Zwiren (1989) identified a short attention span and an unwillingness of children to exert themselves maximally as limiting factors when testing for aerobic power in preadolescents and adolescents (Massicotte & Macnab, 1974). Issues relating to the willingness of investigators to push the children hard may also be a factor.

2.10.7.4 Intensity and specificity of training

The third factor that needs to be considered relates to the intensity and specificity of the training. Rotstein et al (1986) found that a high intensity interval-training program significantly increased maximal oxygen uptake in 10-11 year old boys. These results support other studies in which high intensity training increased VO₂ max in preadolescent and adolescent boys (Rotstein et al, 1986; Ekblom, 1969; Lussier & Buskirk, 1977; Smit et al, 1979; Vaccaro & Clarke, 1978; Von Döbelin & Eriksson, 1973). A lack of improvement in aerobic power seems to align itself with studies that are of an unspecified intensity, low intensity or where the training was not aerobic in nature (Bar-Or & Zwiren, 1973; Daniels & Oldridge, 1971; Stewart et al, 1974). The

training studies referred to in the table all showed improvements to varying degrees with interval training.

2.10.7.5 Specific effects of training

The fourth issue relates to the specificity of training effects. Many authors have found sport training to have a limited effect on maximal aerobic power prior to adolescence (Bar-Or, 1986; Gilliam and Freedson, 1980; Mocellin and Wasmund, 1973; Schmucker and Hollman 1974; Stewart et al, 1974; Yoshida, Ishiko and Muraoka, 1980). Improved athletic performance may be related to neuromuscular factors such as more efficient motor patterns and improved inter and intra-muscular coordination in the growing child prior to adolescence (Beneke et al, 1996; Borms, 1986). Motor coordination and technique improvements rather than a change in VO_2 max are thought to improve performance in children (Mocellin & Wasmund, 1973). This is because with growth, field based aerobic performances can improve without VO_2 maximum changing (Malina et al, 2004).

At this age most sporting tasks are of a sub-maximal nature and therefore using measures of maximal aerobic power to determine improvements in the child's oxygen transport system could be misleading (Malina, 1988). Sport training and high levels of physical activity have been shown to improve sub maximal efficiency but not maximal effort (Lussier & Buskirk, 1977; Stewart et al, 1974). Therefore sport training at this age may have limited affects on aerobic power in the pre-adolescent athlete.

2.10.7.6 Evaluation of the effects of aerobic exercise

In the training studies conducted on untrained adolescents it appears that high intensity interval training has elicited the best responses to increases in VO₂ max (refer to Tables 2.14 and 2.15). Ekblom (1969), Rotstein (1986), Van Döbelin & Eriksson (1973), Koch & Eriksson (1973) and Massicotte and Macnab, (1974) all showed significant increases in VO₂ max with a high intensity resistance program. Docherty, Wenger & Collis (1987) improved but their research was on short bursts of resistance training. Weber et al (1976) showed significant improvements in their paired twins however, the 13 year old trained and untrained twins improved commensurately with the most likely reason being the timing of the adolescent growth spurt, highlighting the impact of growth on training (Weber et al, 1976). Training studies conducted on well-trained adolescents have also shown improvements in VO₂ max (Plank et al, 2005; Kobayashi et al, 1978; Sundberg and Elovaino, 1982). These results highlight the fact that a training intervention on a variety of scales (interval/steady state/high intensity) can achieve a positive response in the adolescent cohort.

It is evident from these studies that aerobic power is trainable in the preadolescent and adolescent athlete, though there is still controversy surrounding the most effective mode (intensity, frequency, duration) of exercise prescription designed to enhance the aerobic capacity of these young athletes (Rotstein et al, 1986). High intensity training is the type of training that is most effective at achieving a positive result amongst the preadolescent and adolescent population. Aerobic power increases with age and is affected to a higher degree around the time of PHV (Kobayashi et al, 1978; Mirwald

et al 1981). Short-term power and peak VO_2 increase at different rates in adolescents even after accounting for maturation (Bloxham et al, 2005).

2.10.7.7 Limitations of VO_2 maximum test protocols

Tests of maximal effort may not be the appropriate measure of aerobic power and VO_2 maximum in children. Considering children's efforts are shorter and often consist of multiple sub-max bursts tests of aerobic power on a treadmill may not give a true representation of the improvements made in the adolescent athlete (Boisseau & Delamarche, 2000).

Table 2.14 Summary of training studies on aerobic activity in males 10-17years old

Key: Experimental group = EG, Control group = CG

Study	Subjects	Gender/n	Age (years)	Training Type	VO ₂ Max Protocol	Pre VO ₂ Max (ml kg ⁻¹ min ⁻¹)	Post VO ₂ Max	Control	Outcome/effect size
Rowland & Boyajian, 1995	Untrained	Males n=13 Females n=23	10.9-12.8	Aerobic activity 30 min, 3 x/wk 12 wks	Treadmill	44.7±5.8	47.6±6.4	No	0.54
Rowland, Varzeas, and Walsh, 1991	Untrained	Females n=14 Males n=1	15.7±0.7	Walking 3x/wk for 11 wks	Treadmill	Endurance time on treadmill 8.82 ± 2.19	10.85± 2.5	No	23% increase p<0.05
Docherty, Wenger & Collis, 1987.	Untrained	Males n=23	11-13	Interval training High velocity-low resistance circuit 3 x/wk 4 wks	Cycle	CG 47±5.0 EG A 46.2±3.4 EG B 47.0±4.9	CG 49.0±6.3 EG A 54.7±4.9 EG B 55.1±6.3	Yes	1.9
Rotstein et al, 1986	Untrained	Males n=28	10.2-11.6 10.79±0.73 EG n=16 CG n=12	Interval 9 weeks 3x/wk for 45 minutes	Treadmill	EG 54.20±3.67 CG 57.13±2.5	58.63±3.85 58.29±3.79	Yes	7% increase with training (absolute) and 8% p/kg/body weight in EG
Mosher et al, 1985	Trained	Males n=24	Males 10-11 EG n=13 CG n=11	3x/wk 15-20min training sessions of varying intensity	1600m run	EG 401.2±5.6 secs CG 438.8±10.6	EG 381.0±6.5 CG 450.8±13.4	Yes	EG decreased time by 20.2 secs compared to 12 secs (mean) CG
Fournier, Ricci, Taylor et al. 1982	Untrained	Males n=12	16-17	Jogging 4x/wk for 3months	Treadmill	58.4 ± 5.6	64.3±5.6	No	5.7% increase check
Sundberg and Elovaino, 1982	Trained	Males EG n=34 CG n=56	12-16 12 yrs CG n=19 EG n=12 14yrs CG n=18 EG n=10 16 yrs CG n=19 EG n=12	Running 40-100km/wk 2-5 years	Treadmill	(12 Yrs) CG 51.1±5.8 EG 59.3±6.2 (14 yrs) CG 56.0±5.1 EG 63.7±4.8 (16 yrs) CG 56.1±5.2 EG 66.4±6.0		Yes	Significant increases in V02max (p<0.01) EG/CG (12 yrs) 1.32 (14 yrs) 1.51 (16 yrs) 1.98

Table 2.14 Continued

Key: Experimental group = EG, Control group = CG

Study	Subjects	Gender/n	Age (years)	Training Type	VO ₂ Max Protocol	Pre VO ₂ Max (ml kg ⁻¹ min ⁻¹)	Post VO ₂ Max	Control	Outcome/effect size
Weber, Kartodihardjo, and Klissouras 1976	Untrained 3 groups of twins	Males n=24	10, 13, 16	Interval/Steady State 10 weeks	Cycle	10 yr-old EG 1.59±0.23 CG 1.58±0.13 13 yr-old EG 2.19±0.20 CG 2.18±2.13 16 yr-old EG 2.95±0.25 CG 2.95±0.40	10 yr-old EG 1.96±0.28 CG 1.77±0.18 13 yr-old EG 2.49±0.17 CG 2.51±0.10 16 yr -old EG 3.55±0.30 CG 3.03±0.22	Yes	10 yr old twins 23.48%+6.12 change in the trained twins 13 yr old twins 14.17%+7.28 change in the trained twins 16 yr old twins 20.53%+0.56 change in the trained twins Significant differences pp<0.02 and p<0.01 in the 10 and 16 yr old trained twins respectively
Massicotte and Macnab, 1974	Untrained	Males n=36	11-13 years T1 n=9 T2 n=9 T3 n=9 T4 n=9	Moderate Medium High Intensity Cycle 12 min 3x/wk 6 wks T1 HR=170-180b/min T2 HR=150-160b/min T3 HR=130-140b/min T4 Control	Cycle	T1 46.7±7.5 T2 47.4±7.8 T3 44.6±6.4 T4 45.7±3.5	T1 51.8±6.0 T2 48.0±6.0 T3 48.2±3.6 T4 44.2±3.1	Yes	T1 2.54 T2 1.20 T3 1.29 Only T1 170-180 recorded a significance of p<0.05
Stewart and Gutin, 1976	Untrained	Males n=13	10-12	Interval running 4 x/wk	Treadmill	EG 49.8±6.1 CG 48.4±4.3	EG 49.5±6.1 CG 49.2±5.2	Yes	0.1
Koch and Eriksson, 1973	Untrained	Males n=9	11-13	Interval running 16 weeks	Cycle	41.7±6.5	48.1±5.0	No	1.10

Table 2.14 Continued

Key: Experimental group = EG, Control group = CG

Study	Subjects	Gender/n	Age (years)	Training Type	VO ₂ Max Protocol	Pre VO ₂ Max (ml kg ⁻¹ min ⁻¹)	Post VO ₂ Max	Control	Outcome/effect size
Eriksson, 1972	Untrained	Males n=12 Series I n=8 Series II n=5	11 Series I n=8 Series II n=5	Series I Interval running and callisthenics 3x/wk for 1 hour for 16 weeks Series II pedalling a bike for 20 minutes 3x/wk for 6 wks	Cycle	Series I 1.87±0.09 Series II 1.93±0.09	2.15±0.12 2.05±0.09	No	Series I improved maximal oxygen uptake significantly p<0.01
Ekblom, 1969	Untrained	Males n=13 EG n=6 CG n=7	11 at the start	Interval, sprint, steady state & strength training 6 months (44 sessions). Ball games (9 sessions)	Cycle	EG 2.15±0.39 CG 2.01±0.26	EG 2.48±0.41 CG 2.07±0.18	Yes	15% increase for the EG. CG remained unchanged

Table 2.15 Cross-sectional studies reporting aerobic capacity in 10-17 year old males

Study	Subjects	Gender/n	Age (years)	Training Type	VO ₂ Max Protocol	Data (ml kg ⁻¹ min ⁻¹)	Control	Outcome/ES
Plank, Hipp & Mahon, 2005	Trained	Males n=9	15.9±1.0 years	Interval/Steady State 13 weeks	Treadmill	65.3±2.9	No	6% increase
Daniels et al, 1978	Trained	Males n=20	10-18	Event specific middle and long distance training 6 years	Treadmill	61.5 mean	No	No change in VO ₂ max. Growth and training contribute to improved performance
Eriksson et al, 1972	Untrained	Males n=13	11-13 years	Interval training Calisthenics Basketball Soccer Series I 4months Series II 6 weeks	Cycle	Series I 1.87±0.89 Series II 1.93±0.09	No	Series I 0.28 l/min or 15% (greater than the growth that took place) Series II 8% increase (due to training as almost no growth took place)

2.10.8 Energy systems in children

Energy systems develop from childhood to adulthood (Robergs & Roberts, 2000). Children are generally more aerobic than anaerobic, with the aerobic capacities of child athletes less developed than adult endurance athletes, but anaerobic capacities are substantially lower than adults (Robergs & Roberts, 2000). Adults can be evaluated for their capacity to be more metabolically aerobic or anaerobic, but metabolic screening of children is not a reliable guide to their adult metabolic capacities. Adolescents are still developing their metabolic capabilities and are not yet metabolic specialists.

In sprint running, the child's performance is distinctly lower than adults due to less ability to generate mechanical energy during short-term intensive exercise and intramuscular high-energy phosphate kinetics vary along with muscle cross sectional area in the developing child (Van Praagh, 2000; Ferretti et al, 1994).

Therefore, performance amongst the adolescent cohort is different when compared to adults as represented by lower performance on anaerobic tests, less efficient, and less additional anaerobic energy at the end of the test.

2.10.9 Adolescent's capacity to adapt to a training program

Compared to adults, children may have less capacity to adapt for a number of reasons. A lower anaerobic threshold, a lower level of lactate in the working muscle, an increased oxygen cost of locomotion, a lack of precise coordination, lower levels of strength and endurance and less capacity to develop specialisation, all impact upon the adolescent athlete and their ability to adapt to a training program.

There are training related-safety concerns in terms of total training volume and potential, overuse however the justification for such claims is weak. There is social pressure not to overstress. Adolescents have been shown to adapt better than preadolescents. Indoor and outdoor sprint tests reveal better performance during growth period (Boisseau & Delamarche, 2000). These data reinforce the notion of 'optimal periods' for speed capacities.

2.10.10 Importance of speed to adolescent sports performance

Sports such as rugby league, rugby union, soccer, Australian rules, tennis, basketball and hockey all require the athlete to produce short bursts of speed at a maximal or near maximal pace repeated regularly over an extended period of time (70-120 minutes) (Dawson et al 1993; Fitzsimmons et al 1993; Tharp et al, 1985). As children and adolescents are involved in a variety of these sports it stands to reason that speed and power and their development are essential components of success in many sports (Young et al, 2001; Fitzsimmons et al, 1993; Stone et al, 2003, Stone et al, 1998). It is not just speed that is important but the ability to repeat it. This special type of speed endurance is called repeat sprint ability (RSA) (Fitzsimmons et al, 1993; Bishop & Spencer, 2004; Newman et al, 2004). All team sports require RSA, and as speed forms the platform for RSA, it is important that coaches recognise the multi dimensional qualities of speed performance. This will allow coaches to define performance models that will enable a thorough implementation of systematic programs to improve an athlete's speed capacity. Furthermore, speed-training programs can assist in the development of more efficient motor patterns that can lead to a better use of an athlete's energy potential (Verkoshansky, 1996).

2.11 Summary

There is strong evidence to suggest that children can adapt to a training program (Tables 2.10, 2.11, 2.12, 2.13, 2.14, 2.15) although training has produced improvements in some but not all studies. Strength gains have been shown to be substantial in pre adolescents and adolescents. Aerobic improvements have been noted with both high intensity and steady state training but more research is required to accurately assess the trainability of this cohort (Rotstein et al, 1986). Speed and plyometric training have been shown to improve performance in adolescent athletes although few studies have been undertaken in this area.

Therefore, further investigations that improve our understanding of the effects of different types of speed and plyometric training would be beneficial to adolescent athletes and their coaches.

Limitations that surround the adolescent athlete (mechanically inefficient, lack of precise coordination, metabolic non-specialists, increased cost of locomotion, smaller limb lengths) must be considered for a safe and effective training program to be implemented. Growth, maturation and development are additional factors that can affect an adolescent's ability to adapt to a training program.

Chapter 3

Methods

3.1 Study design

The aim of this study was to determine whether sprint training alone or a combination of sprint and bounds training improves running speed over a distance of thirty metres in adolescent rugby league players. The responses of these two types of training were compared to a third group who undertook rugby league fitness training. Three groups of subjects, a fitness group and two intervention groups, who undertook different nine-week training programs, took part in the study. The participants were tested at the beginning of week one (pre-training) and in week ten (post-training).

3.2 Subjects

Junior male rugby league players from a selective sports high school were recruited to participate in the study. An information evening was held at the high school, to inform both participants and parents about the study. Participation in the study was voluntary. The University of Newcastle Human Research Ethics Committee (HREC Number: H-529-0303) approved all the procedures undertaken, and all subjects and one of their parents signed an informed consent form prior to participation. Also, the study was approved by the New South Wales Department of Education and Training (SERAP Number: 03.76).

Criteria for each student's participation was that he could not have participated in any specific sprint training in the six months prior to the study or undertake any extra sprint training during the study itself. The subjects were randomly assigned by way of

computer program into one of the three groups: the fitness (F) group, the speed-training group (S), and the speed and bounds (SB) training group.

3.2.1 Health screening questionnaire

Participants were asked to complete a health questionnaire (Appendix A), which asked questions regarding the health status, physical activity level, and injury status of the individual. Participants were screened using this questionnaire with relation to their health status and therefore their ability to take part in the study.

3.3 Exercise Testing

Testing was undertaken in week one (pre-training) and week ten (post-training). Subjects trained after the testing in week one however as week nine was the last training week, there was no subsequent training after testing took place in week ten. First each subject was given two attempts at sprinting as fast as possible over thirty metres. A recovery period of at least five minutes was maintained between attempts. Subjects then performed two sets of ten double-legged bounding jumps, also separated by at least five minutes recovery.

The rationale for performing the speed tests first was that the main focus of the study was to determine whether speed training alone or a combination of speed and bounds training improved speed over thirty metres. Bounding first may have introduced an element of fatigue to the subjects and adversely affected the speed results.

3.3.1 Warm-up and cool down

All groups performed the same standardised warm up protocol prior to each training session (Tables 3.1 and 3.2). This consisted of five sprint drills completed once each, three specific ballistic stretching movements repeated twice for each leg, and a series of static stretching exercises. The subjects warmed up in light trainers but performed all training in football boots. The major muscle groups were stretched at the end of each session.

Table 3.1 Warm up drills performed at the beginning of each training session

Specific Drill	Type	Focus
Wall slide	High knees/heels flick	Active heel recovery/arms
Butt kicks	Touch butt with heels	Snapping movements
B skip	Knee to knee separation	Gluteal innervation/drive through hips
A skip	Lift knee's over imaginary hurdle/foot strike underneath COG	Rhythm
Accelerations	Building up to speed over 30-40 m	Striding/changing gears

Table 3.2 Ballistic stretching performed after the warm up drills

Specific Movement	Number of Reps	Focus
Lateral leg swings	2 by 10 each side	Core stability/mobility
Kicking leg swings	2 by 10 each side	Core stability/mobility
Ballistic gluteal swing	2 by 10 each side	Core stability/mobility

3.3.2 Speed and bounds testing conditions

The participants performed all tests wearing football boots. Both the sprint and bounds tests were performed on the school grass running track. The grass running track was cut to the same level for each of the weeks during the study and all training and testing commenced at 8am with similar surface conditions on each occasion, including slight dew covering the grass.

3.3.3 Timing of sprints

Thirty metre sprint times were measured by the SpeedProbe (Onspot, University of Wollongong, Wollongong, NSW) electronic timing device to the nearest one-hundredth of a second. Times were obtained for 10 m splits over a 30 m distance. Cones were placed at 10 m intervals to signify the 10 m split. The best time was used for data analysis. The SpeedProbe uses a segment of fishing line attached to the back of the shorts of the subject and timing begins once the first movement occurs. A limitation of this device is that reaction time is not obtained due to the fact that timing begins when the subject moves and is not governed by an external stimulus such as a starting gun or signal. Consequently, the times obtained may be faster than those of studies that use an external stimulus to initiate movement. In sports where rolling starts and anticipation cues are common, such as rugby league, the inability to include a reaction time component in the 30 m time was not considered important.

3.3.4 Measurement of bounding distance

The distance covered by 10 double-legged bounding jumps was measured to the nearest tenth of a metre using a standard measuring tape. Two assistants determined the 10th landing point closest to the starting position. The distance from this landing point to the start line was recorded for each attempt.

3.4 Training

Separate training sessions for fitness, speed, and bounds were conducted once a week for 9 weeks. Fitness and speed sessions took place at 8am on Tuesday mornings and lasted approximately one hour. Bounding sessions took place at 11.45am on Thursdays and lasted approximately 45 minutes. Group F performed only rugby

league fitness training (Table 3.5), Group S performed only speed training (Table 3.3), and Group SB performed both speed training and bounds training (Table 3.3 and 3.4). The sprint and bounds training programs were based on the principles outlined in section 2.8.

Table 3.3 Sprint training program (total volume 3490 metres)

Weeks	Mode	Repetitions	Distance (m)
1/2/3	Starts (standing)	4	5,10,15
	Wind sprints	4	40/30
	Hollow runs	4	20/20/20
	Tempo <85%	5	40
4	Starts (falling)	4	5,10,15
	Fly in sprints	3	10/10
	Fly in sprints	3	15/10
	Hollow runs	4	20/20/20
	Tempo <85%	3	40
5	Starts (falling)	3	5,10,15
	Fly in sprints	2	10/5
	Fly in sprints	2	20/10
	Acceleration runs	5	60
	Tempo <85%	3	40
6	Acceleration runs	3	40
	Tempo <85%	5	60
7	Starts (standing)	3	10,15,20
	Wind sprints	3	40/30
	Fly in sprints	2	10/10
	Tempo <85%	5	60
8	Starts (standing)	3	10,15,20
	Fly in sprints	2	10/10
	Fly in sprints	2	10/15
	Hollow runs	3	20/20/20
	Tempo <85%	4	60
9	Starts (falling)	2	10,15,20
	Fly in sprints	2	10/10
	Fly in sprints	2	10/15
	Fly in sprints	2	10/20
	Tempo <85%	3	60

Table 3.4 Bounds training program (total volume 450 foot contacts)

Weeks	Mode	Repetitions	Foot contacts
1/2/3	Double leg bound	2	10
	Alternate leg bound	2	10
	High bound	2	10
4	Double leg bound	2	10
	High bound	2	10
	Speed bound	2	10
5	Double leg bound	2	10
	High bound	2	10
	Speed bound	2	10
6	Rest		
7	Double leg bound	1	10
	Borzov jump	2	10
	High bound	2	10
8	Rest		
9	Double leg bound	2	10
	Borzov jump	1	10
	Alternate bound	1	10
	High bound	1	10

Table 3.5 Rugby league fitness program (total volume 45-60 minutes)

Week	Training
1	Tackling bags, skills, tempo <85%
2	Boxing, touch football
3	Skills, set plays, tackling bags
4	Boxing
5	Flexibility
6	Skills, tempo running <85%
7	Boxing, tackling bags, skills
8	Boxing, tackling bags, skills
9	Boxing tackling bags, skills

3.4.1 Fitness training

Group F performed a series of football specific drills with no specific speed-training component but there were incidental sprint efforts in this training (Table 3.5). This training consisted of a series of tackling drills, ball skills drills and a game of touch football to complete the session. Stretching of the major muscle groups was performed at the end of each session.

3.4.2 Speed training

Groups S and SB performed a series of three-point (moving from inertia) falling and rolling starts, wind sprints (running a short distance then repeating the effort with minimal recovery), hollow runs (running and holding the speed through a set of markers then accelerating again utilising elements of speed play), fly in sprints (building up speed and aiming at maintaining maximal velocity through a short segment) and tempo runs (sub-maximal efforts over distances of no more than sixty metres) (Table 3.3). The recoveries for each speed effort were approximately sixty seconds and the time between sets was no more than a couple of minutes. Most sprints were over <30 m although each session contained some sprints over 40 m or 60 m. Specific instructions given to participants were to increase stride length to maximum and then concentrate on turnover and bounce, and to emphasise rear side dynamics throughout acceleration.

3.4.3 Bounds training

Bounds training was performed two days after speed training (Table 3.4). The bounding routine comprised a series of single-legged hops, double-legged hops and assisted single-legged hops. The training volume for these exercises was based on

foot contacts over the course of the session. Each bounding exercise consisted of no more than 10 foot contacts and the total volume was no more than 60 foot contacts per session. The number of foot contacts was reduced to 50 during week 7, and no bounds training was performed in weeks 6 and 8 due to concern over complaints of shin soreness. Specific instructions given to participants were to react fast off the ground and attempt to take off at a forty-five degree angle in relation to the ground. Bounds were performed on a grass running track on the school oval. The suitability of bounds training for this population was deemed appropriate for three specific reasons. Firstly, all bounds undertaken were assessed to be at the medium-low end of the scale in relation to ground reaction forces (Chu, 1998). Strength bounds in which the amortisation phase is longer leading to more pressure on the muscles, bones and joints were not used (Chu, 1998; Lundin & Berg, 1991). Secondly, plyometric training studies on the adolescent population had used similar bounds exercises (Table 2.12) and reported significant findings with no compromise in safety. Thirdly, bounding has been identified as having a high significance in relation to the speed strength capabilities of the athlete, which directly link to acceleration (Vittori, 1996).

3.5 Statistical analysis

Statistical analysis was performed using SPSS for Mac (version 13.1). The independent variables were group (F, S, SB) and time (pre and post-training). To compare the groups prior to training a one-way analysis of variance (group) was performed. To determine the effect of training a two-way analysis of variance was performed, followed by post-hoc paired t-tests to allow pairwise comparisons when significant interactions were found. Significance was set at $p < 0.05$. Effect sizes were calculated to evaluate the meaningfulness of observed changes. This analysis was

performed using the statistical spreadsheets of Hopkins (available at <http://www.sportsci.org/resource/stats/index.html>). The criteria for interpreting the magnitudes of effects were based on a modification of Cohen's Effect Size classification system: 0.0-0.20 trivial; 0.2-0.6 small; 0.6-1.2 moderate; 1.2-2.0 large; >2.00 very large (Batterham & Hopkins, 2006).

Chapter 4

Results

4.1 Participants

Sixty-seven junior male rugby league players were recruited to participate in the study. Recruitment took place three weeks prior to the study commencing. By the pre-training testing session, seven participants had left the rugby league program and therefore did not participate in the study, leaving sixty subjects. Of these sixty subjects, fourteen sustained game-related injuries the weekend prior to the study that prevented them from participating. Forty-six participants commenced the study (Table 4.1). The groups did not differ significantly in age: Fitness (F) 14.5 ± 1.1 ; Sprint (S) 15.1 ± 1.7 ; Sprint-Bounds (SB) 14.8 ± 1.5 years. Forty-two participants completed the study.

Table 4.1 Numbers of participants per group across study

	Fitness	Sprint	Sprint-Bounds	Total
Group assignment	22	22	23	67
Completed	12	12	18	42

Data are numbers of participants.

4.2 Attrition

All attrition once the study had commenced was due to game-related injuries. There were no injuries sustained as part of the training or test protocol administered to the participants. Some of the participants completed the speed testing but did not complete the accompanying bounds testing due to concerns relating to post-game muscle soreness. This accounts for the slightly smaller numbers that completed the bounds testing.

4.3 Attendance at training

For groups F and S, no participant missed more than two training sessions. For group SB, no participant missed more than two speed sessions or two bounds sessions.

4.4 Comparison of groups prior to training

Although there were no statistically significant ($p < 0.05$) differences in pre-test performance among the groups, there were small differences in mean sprint times among the groups over 10 m ($p = 0.078$) and 30 m ($P = 0.054$) but no differences in bounds performance ($p = 0.755$). Over both sprint distances, group S had faster mean sprint times than groups F and SB (Table 4.2). Although small, these differences are likely to be meaningful in terms of sprint performance, and may have impacted on the capacity to respond to training. Differences between groups S and F were smaller (~3%) than between groups S and SB (5-6%) over 10 m and 30 m sprint distances; the difference between groups F and SB was ~2%.

Table 4.2 Comparison of performance results of groups prior to training

	Fitness n=12	Sprint n=14	Sprint-Bounds n=20
10m	2.08	1.99	2.09
	± 0.14	± 0.13	± 0.14
30m	4.90	4.69	4.94
	± 0.18	± 0.25	± 0.38
Bounds	20.7	20.9	20.3
	± 1.5	± 2.2	± 2.3

Data are means \pm SD.

4.4.1 Analysis of responses to training of completers

This analysis was conducted on data from participants who completed the training and both pre and post testing sessions (Tables 4.4 and 4.5). Overall the results of the completers analysis are very similar to those of the intention-to-treat analysis, with

significant interactions ($P=0.007$) between time and group for the sprint times but not the bounds distances.

Table 4.4 Responses to training from completers analysis

	Fitness Group n=12		Sprint Group n=12		SB Group n=18	
	Pre	Post	Pre	Post	Pre	Post
10 m	2.06	1.95*	1.98	1.94	2.10	1.99**
	± 0.12	± 0.05	± 0.13	± 0.12	± 0.15	± 0.11
30 m	4.88	4.68**	4.71	4.75	4.95	4.77**
	± 0.17	± 0.14	± 0.25	± 0.41	± 0.39	± 0.28
Bounds	20.9	22.3**	20.9	22.3**	20.2	22.3**
	± 1.5	± 1.3	± 2.4	± 2.0	± 2.4	± 2.3

Data are means \pm SD. * $p<0.05$, pre-post changes

** $p<0.01$

Table 4.5 P-values for responses to training from completers analysis

	Fitness Group n=12	Sprint Group n=12	SB Group n=18
10 m	.011	.310	.001
30 m	.001	.704	.001
Bounds	.003	.001	.001

Data are p-values.

An additional effect-size analysis was conducted on the data from those completing the study. This analysis places more weight on the magnitude of any effect and allows categorisation of the magnitude of any effects as trivial, small, moderate and large.

The results of this analysis are shown in Table 4.6. The S group showed consistently smaller responses to training compared to the other groups, and the fitness group showed consistent moderate-sized improvements.

Table 4.6 Effect-sizes of responses to training, descriptive categorisation of size of effects of responses to training

	Fitness Group n=12	Sprint Group n=12	SB Group n=18
10 m	0.80	0.27	0.75
	moderate	small	moderate
30 m	1.10	0.11	0.45
	moderate	trivial	small
Bounds	0.93	0.57	0.83
	moderate	small	moderate

Descriptors are modifications of Cohen's effect sizes as described in section 3.5.

Chapter 5

Discussion

5.1 Introduction to discussion

All three training programs led to improvements in sprint speed and bounds distance, but the extent of the improvements varied with the training program and pre-training performance level. Groups F and SB had 4-5% improvements in sprint speed whereas group S showed relatively trivial changes. In all groups, the improvements were greater over 10 m and least over 30 m sprint distances. Bounds distance improved more than sprint speed and the greatest improvement was observed in the sprint-bounds group.

In this chapter, I will discuss the influence of pre-training testing on performance, training effects on 10m and 30m speed, training effects on bounds performance, growth and maturation and the limitations of the study.

5.2 Participants and attrition

Injuries sustained in school and weekend rugby league competition accounted for the entire attrition. There were no injuries sustained as part of the training or test protocol administered to the participants. Some of the subjects were able to complete the speed testing but were not able to complete the accompanying bounds testing due to soreness specific to bounding. This accounts for the slightly lower number of players that completed the bounds testing.

5.3 Influence of pre-training sprint speed on responses to training

There were clear differences in the improvements in sprint speed to training programs among the three groups. These differences could be due to the different training undertaken but are also likely to have been influenced by pre-training differences in sprint performance among the groups. In this study, players were randomly assigned to a group prior to pre-training testing. Therefore there was no knowledge of differences in sprint speed among players and no capacity to stratify the allocation of players to groups. By chance, more players with faster sprint speeds were allocated to group S and fewer players with fast sprint times to group SB. Consequently, the scope for improvement in sprint speed was greatest for those in group SB and least for those in group S. A recommendation for future studies is to stratify the allocation to groups based on pre-training sprint speed.

5.4 Influence of pre-training bounds performance on responses to training

There were differences in improvements in bounds performance among the groups, which may also reflect scope for improvement. The SB group improved the most (10% versus 7% for both other groups) with training and this may reflect the greater scope for improvement in this group.

5.5 Training effects on 10 m and 30 m speed

All groups improved 10 m speed. Moderate improvements (5%) were observed with both the F and SB groups, and small (2%) increases in speed were observed in the S group over 10 m. Speed improvements over 30 m differed more among the groups ranging from moderate (4%) increases in the F group, small (3%) increases in the SB group and trivial (<1%) change in the S group.

All groups improved 10 m speed more than 30 m speed. The greater improvement over the 10 m compared to the 30 m distance suggests that the training programs had more effect on initial acceleration than later acceleration and maximal running velocity. Possible reasons for this are twofold. Firstly the training program focussed mainly on accelerations over distances of < 20 m and maximal velocity running (fly-in sprints) over distances of 10-20 m. It would be reasonable to expect that the program would improve speed over 0-10 m more than 0-30 m preferentially because all sprinting involves a sprint through this distance and as such the volume of running is high in this segment. These findings support Kotzamanidis (2003) who found that a sprint-training program utilising distances of 5-30 m over a 10-week period improved speed over 0-10 m and 10-20 m, but not 0-30 m. This study and that of Kotzamanidis (2003) found an improvement in the acceleration phase but not the phase where maximal velocity would tend to be achieved. Running maximally over distances of 30 m and beyond may be required if 0-30 m speed is to be improved substantially. Furthermore, starts from a standing position were predominately used as opposed to falling, rolling or striding starts so it can be reasoned that starting from a standing position requires the athlete to overcome inertia which is linked to initial acceleration.

Secondly, the bounds training undertaken by the sprint-bounds group reflected a longer stretch shortening cycle (SSC). Activities such as jumping utilise a longer SSC and sprinting utilises a short SSC. Therefore, the improvements in SSC may not have had an immediate effect on speed performance in the sprint-bounds group. Also, the training of the longer SSC may have affected the acceleration components more than the maximal velocity components of the athletes concerned. Activities that use a short SSC such as depth jumping, which correlate more with maximal velocity running,

were not undertaken due to the age of the athletes and injury concerns amongst developing athletes.

5.6 Training effects on bounds performance

All groups improved bounds performance. The S and F groups improved to the same extent (7%). The SB group improved more (10%) which may be attributed partly to lower pre-training performances but also to the specific bounds training which only this group performed. Prior to training, the F and S groups were 3% better on average than the SB group. After training, no differences were observed between the groups, suggesting an influence of training specificity in the SB group. These findings support other studies in which plyometric training improved jump, power and running velocity significantly in the adolescent cohort (Kotzamanidis, 2006, Ingle et al, 2006, Matavulj et al, 2001, Diallo et al, 1999, Diallo et al, 2001; Brown et al, 1986)

As bounding for this cohort of athletes was a less familiar activity than sprinting, it is possible that some of the improvements in bounds performance could relate to familiarisation with the task as opposed to the effects of the training intervention. All three groups improved between tests, and the sprint-bounds group made only slightly greater improvements than the other groups.

5.7 Training program-specific effects on sprint speed and bounds performance

5.7.1 Effects of fitness training on sprint speed

The F group showed moderate improvements in sprint speed over 10 m and 30 m. It was the most effective of the training programs over 30 m. The F group performed a variety of repeated efforts utilising tackling bags over 10 m, various skill sets over 50

m, touch football, boxing and some longer efforts of 60-70 m. These over distance efforts and the repeat sprint ability (RSA) required of them may have contributed to the greater effects on 30 m speed. This suggests that rugby league specific fitness training that consists of a variety of repeated efforts such as short sprints, various skill sets over 50 m, touch football, longer efforts of 60-70 m, boxing and mobility work can be effective in improving both 10 m and 30 m sprint speed in adolescent players. The rugby league training used shorter recoveries and longer distances than the sprint training and these factors may have led to improvements in 30 m speed.

Mero (1992) also found that a variety of non-specific activities improved anaerobic performance on 15 s and 60 s sprint cycle tests in adolescent boys. Christou et al (2006) found that soccer training improved strength parameters more than normal growth in adolescent boys. This highlights the point that during adolescence a variety of activities may give similar results to a specific intervention. Mero (1998) identifies improvements in stride length, which relate to muscle CSA and strength, as the reason for the differences in speed in adolescent boys. Therefore improving strength, which improves stride length, may improve speed in this cohort.

5.7.2 Effects of fitness training on bounds performance

The F group showed a moderate improvement in bounds performance. This improvement may partly reflect task familiarisation, as this group undertook no bounding training. Alternatively, adolescents involved in sports, especially rugby league, are already doing high-powered muscular work that utilises the SSC in the developmental stages (Mero, 1998). This work may in fact lay a platform for further bounding improvements. A variety of activities undertaken during childhood and

adolescence have been shown to improve strength, enhance muscle fibre area and improve the capacity for anaerobic work (Mero, 1992, Hakkinen et al, 1989)

5.7.3 Effects of sprint training on sprint speed

Sprint training alone was the least effective of the training programs for improving 10 m and 30 m sprint speed in this study. This may be linked to pre-training superiority and the consequence that the sprint group had less scope to improve. Although improvements were small, the sprint group still reported the fastest post-training times over 10 m. Training twice or three times a week may be needed to obtain further improvements in a cohort that already has fast sprint speed times over 10 m and 30 m. Furthermore, the training program may require a greater proportion of over-distance work beyond 30 m at speed to generate improvements in 30 m speed. This is supported by the only other published study where controlled sprint training was undertaken (Kotzamanidis, 2003). Kotzamanidis (2003) found that training over distances of 5-30 m only improved 0-10 m, 10-20 m but not 20-30 m times.

5.7.4 Effects of sprint training on bounds performance

The S group improved almost as much as the F and SB groups in bounds performance. Sprinting requires the athlete to apply force in a short amount of time utilising the SSC (Mero & Komi, 1994). The S group were the fastest sprinters amongst the groups and therefore may have already established ability to utilise their SSC and this may have been reflected in the improvements made in bounding performance. Furthermore, short sprint training may use the SSC in such a way that it improves bounding.

5.7.5 Effects of sprint and bounds training on sprint speed

The combination of sprint and bounds training produced moderate improvements in 10 m speed and small improvements in 30 m speed. This group was the slowest prior to training and responded well on 10 m times reflecting the focus of the sprint training. It is not clear whether the greater improvements in 30 m times compared to the sprint group are a consequence of slower pre-training times, a combination of scope to improve and training effects, or reflect in part the fact that they trained twice a week.

5.7.6 Effects of sprint and bounds training on bounds performance

The SB group showed the greatest improvement in bounds performance. This group reported the lowest pre-training values for bounds performance but improved to a level comparable to the other groups. These findings support other studies where power performance improved through plyometric training (Kotzamanidis, 2006; Ingle et al, 2006; Matavulj et al, 2001; Diallo et al, 1999; Diallo et al, 2001; Brown et al, 1986). Furthermore, these studies suggest improved force of the hip extensors and improved rate of force at the knee extensors. Over a distance of 30 m, it is possible that maximal velocity would be reached in adolescent team sports athletes unlike adult sprinters (Kotzamanidis, 2006, Branda et al, 1984). Therefore the SB group who undertook both sprint and plyometric training may have shown a greater improvement due to improvements in power generation or more time in training specificity.

Cavagna et al (1971) identified power to reach a maximum at $5 \text{ m}\cdot\text{s}^{-1}$ and after this the speed relates to the elastic energy of the muscle. The plyometric intervention may possibly have provided the athletes with improved contractive assistance over this distance as displayed by faster times. However, whilst sprint running involves power

components, it also requires a combination of coordination, stride frequency, stride length, flexibility, mobility, anaerobic endurance, aerobic endurance and energy provision. Therefore, improving one area, it still has to be synthesised into the 'total' sprint performance, and may not necessarily improve performance.

Lagtime, which is the time taken for the athlete to use the new skill or performance variable, may have affected the SB group (Stone et al, 2003). It may have taken more time for this group to utilise the improvements made in bounds and the SSC, before they were reflected in the 10 m and 30 m sprint times.

5.8 Limitations of the study and recommendations

5.8.1 Group stratification prior to group assignment

As mentioned earlier, assessing sprint speed prior to group assignment and stratifying assignment would be recommended for future studies. No height, weight, limb length or other anthropometric data were measured in this project and there was no tracking of changes in body structure over the study. Also no attempt at estimating stage of maturation, such as self identified tanner staging, was undertaken. It is possible that growth and maturation changes occurred over the course of the study and contributed to some of the improvements in performance observed. However, it can be argued that 9 weeks was not enough time to have aspects of growth, maturation and development impact substantially on sprint performance.

A familiarisation period would be recommended for future bounding studies in adolescents or those not familiar with bounding. All groups improved bounds performance and this may have been in part due to improved motor coordination for

the task, rather than the intervention (Malina et al, 2004). Whilst this program proved to be a safe training intervention, a more frequent training program, possibly 2-3 times a week may be required to elicit a greater response in this cohort. There were no injuries due to the training intervention in this study.

Children and adolescents will improve speed and power throughout the developmental stages. Therefore many-sided activities that promote aspects of speed and power such as rugby league training should be encouraged if the objective is to improve speed and power variables over short distances. Specialist sprint training does not appear to be necessary in this population to improve sprint speed.

5.9 Future directions

Researchers could examine the influence of a more frequent training on sprint speed in adolescents. The influence of training over longer distances on 10 m and 30 m may provide researchers with a valuable tool in delineating the effects of training as it relates to acceleration and maximal velocity. Differences in responsiveness between early adolescents (12-14years) compared to (16-18years) could be examined. This may provide further insight into the effect of growth and maturation as well as training regimes have on sprint speed.

Furthermore, the influence that gender has on sprint speed could be examined. As girls mature at an earlier age than boys, it is not uncommon that in the developmental stages, girls of the same age are faster than boys. Mero (1993) suggests neuromuscular performance in power athletes increases more in males than females in late puberty when the amount of training is similar.

Finally, the influence of training on a variety of surfaces and how it relates to team sports would be advantageous with respect to injury management and training.

5.10 Conclusion

This study has demonstrated that a range of training programs may be effective in improving sprint speed in adolescent team sport athletes, with minimal risk. However some players were sore from the bounding. Both pre-training performance and training program influence the responses. For adolescent team sports athletes, sport-specific fitness training may be as effective as dedicated sprint training sessions to improve speed over short running distances. In addition bounds training may selectively improve the acceleration phase rather than the maximal velocity phase in the adolescent athlete (Kotzamanidis, 2006). Bounds training may need to be used irregularly to maximise improvements.

Appendices

Appendix A
Ethics Documents

Attention: Principal
Re: Test procedures for students

I am completing my masters degree by research at the University of Newcastle under the supervision of Dr Robin Callister. This involves training & testing a variety of school aged athletes with regards to strength power and speed. I am therefore asking your permission as Principal of ##### to recruit students at the school to participate in this project.

The students would be selected upon the basis of the following criteria:

1. Involvement in a team sport which requires them to train at least twice a week.
2. Must not have participated in power or speed training more than once a week previously in the past year.
3. Fall in the age group of 12-17yrs

The testing would take place at school but not in school time. There will be two groups comprising of students that fall into similar categories for the purposes of the testing procedure. There will be a pre-test and post-test evaluation. The proposed time period would be one hour a week for 10wks in term 3. Of the two groups one group will perform a speed related program and the second group will perform the same speed related program with the variable being, the second group will perform power type exercises once a week as well. All sessions will be organised and administered by myself under the supervision of Dr Robin Callister.

All of the information and procedures regarding this test protocol will be examined by the University of Newcastle Human Research Ethics Committee (HREC) and the testing will only go ahead after permission by yourself and the HREC. I am providing you with all of the relevant documentation and questionnaires regarding the study. If there are any questions regarding the study and its implementation at your school please do not hesitate to call myself or Dr Robin Callister at The University of Newcastle.

Thanking you for your time

Mr Cale Wallace

Ph. 49435755

Dr Robin Callister

Ph. 49215650

Dear Parent/Guardian

My name is Mr Cale Wallace and I am conducting professional research for my Masters in Exercise Physiology at The University of Newcastle. As part of this research I am required to undertake a testing procedure on a variety of school aged athletes. The testing will involve a 10 week speed and power training program that has been approved by the Hunter Area Research Ethics Committee (HAREC) and has the Principal, ##### approval.

The trial will be for 1hour a week for group one. And 2 hours a week for group two. The trial is focussing upon what degree does power training affect the parameters of a 30 metre speed interval amongst junior athletes. The trial will not be involved in school time but will be conducted before and after school.

I will be training and testing all athletes for one specific day each week for the entirety of term two. I will form the groups for the test protocol based on the following criteria:

1. Involvement in a sport which requires them to train at least twice a week.
2. Not having participated in power or speed training more than once a week previously in the past year.
3. Fall in the age group of 12-17yrs

A pre-pubertal questionnaire will accompany the testing to ascertain the particular stage of development that a particular child is at. This is essential to eliminate bias. For example one child may be more powerful than another solely based upon stages of development.

If you consent for your child to be part of the trial please fill out the consent form and return it to me at #####. If you have any further questions or queries that you need answered please either contact myself at school or Dr Robin Callister at The University of Newcastle.

Thanking you for your time

Mr Cale Wallace

Dr Robin Callister

I (Print Name)_____ consent for my child

(Print Name) _____ to participate in the trial conducted by Mr Cale Wallace under the supervision of Dr Robin Callister with regards to speed and power training. I understand that the test results will be used for the purposes of study. I also consent for my child to train with Mr Cale Wallace for one and two hours a week for the entirety of term two.

Signed Parent/Guardian

Research Project Information Statement

(To be retained by the participant)

Project Title: Training for improvement in running speed in junior/young athletes.

Research Student: Cale Wallace

Research Supervisor: Dr Robin Callister

You are invited to take part in a research project which involves training for improvements in running speed. The project will take place at #####. This project is for the Masters project of Cale Wallace, and will be conducted by Mr Wallace under the supervision of Dr. Robin Callister.

Aim of the project

Whether sprint training alone increases running speed in young athletes and whether a combination of sprint training and plyometric training results in greater increases in running speed than sprint training alone.

Reasons for doing the project

Speed is an important component in many sports. We are aiming to find out the best way to develop speed in young athletes. We are interested in comparing a group that just does speed training with a group that does speed training as well as plyometric training. After the study we may be able to identify the particular type of speed training that would be most beneficial in the early stages of training for athletes.

Freedom of consent

Your participation in this research is voluntary. You may decide you don't want to be in it. If you choose to be in it, you may change your mind before the project start or at any time during the project. You just need to tell us that you wish to stop and do nothing more.

Inquiries

On the next page is a general outline of what participating in this project involves. Much more detailed information about what is involved is in the next section. You should discuss this information with your parent or guardian. If there is anything that you don't

understand but would like to ask, you may phone Cale on (02) 49435755 or Robin on (02) 49215650

What is involved in this project?

Before coming to the training you will be asked to fill in a questionnaire with the help of your parents. There are general questions about your health, your participation in previous speed/power training, and your stage of physical growth or maturity. We will give you several drawings of what children look like at different stages of growth. You just tick the picture that looks like you and put it in an envelope.

What will you be doing during your training and testing?

During training you will be doing speed specific training. It will involve a warm up, a speed training session and a warm down. The group that is also doing the plyometric training will complete a series of jumping exercises that will complement the speed training. Under no circumstances will any form of resistance or weight bearing apparatus be used. The exercise tests will involve a series of sprints up to 30 metres and a series of bounds up to 30m. The sprints will be tested electronically and the bounds using a tape measure. The sessions will all be on grass with alternate arrangements made if it rains.

Before you decide

There is more information in the next section. You should go through this with your parents to ensure that you want to go ahead with the training.

Research Project Information Statement

(To be retained by the parent or guardian of the participant)

Project Title: Training for improvement in running speed in junior/young athletes.

Research Student: Cale Wallace

Research Supervisor: Dr Robin Callister

Your child is invited to participate in the research project mentioned above. The project will take place at ##### and the people conducting the project will be Mr Cale Wallace & Dr. Robin Callister.

Aim of the project

Whether sprint training alone increases running speed in young athletes and whether a combination of sprint training and plyometric training results in greater increases in running speed than sprint training alone.

Reasons for doing the project

Speed is an important component in many sports. We are aiming to find out the best way to develop speed in young athletes. We are interested in comparing a group that just does speed training with a group that does speed training as well as plyometric training. After the study we may be able to identify the particular type of speed training that would be most beneficial in the early stages of training for athletes.

Freedom of consent

Your child's participation in this research is voluntary. You may decide you don't want them to be in it. If you choose to allow your child to participate, you may change your mind before the project starts or at any time during the project. You just need to tell us that they wish to stop and do nothing more.

Inquiries

Questions concerning any aspect of this project are welcome at anytime. You may direct your questions towards Mr Cale Wallace (02) 49435755 or Dr. Robin Callister (02) 49215650

Research Project Information Statement (Continued)

What participation involves

If your child chooses to participate in the project it will involve the following:

1. Questionnaire

The participant under the supervision of his/her parents will be asked to complete two questionnaires. The first one is a check on what level the participant has been exposed to speed training within the past year and the other is a stage of maturation questionnaire that will indicate the level of physical development that the child has attained at the stage of testing.

2. Training

The participant will be asked to attend a 1hr training session for speed training each week for 9wks. If the participant is in the speed and plyometric group they will be asked to complete a 1hr training session for speed training and 1hr session for plyometric training each week. The speed training will involve short, sharp bursts or efforts that aim to complement the training already being completed by the child's respective club teams. The plyometric sessions will involve bounding movements of differing intensities over distances of 30m maximum. At no stage during the testing will any elements of resistance (weight bearing) apparatus be used.

3. Testing

Testing will take place before the commencement of training on wk 1 (pre-training), in the 6wk interval (mid-training) and at the completion of the program in wk 10 (post-training). The testing procedure is clear and straight forward. For the speed test students will use a machine that is called The Probe. A piece of fishing line is attached to a piece of clothing on the student and as they run over the distance the probe will record the speed of the athlete. The plyometric testing will involve students performing a variety of bounds over distances no more than 20 metres on a grass surface. The child's efforts will be measured by a tape measure.

4. Equipment and Attire

Participants will need to wear clothing appropriate for running and footwear should have either spikes or football type boots. A water bottle and towel are essential.

5. Risk and Discomfort of Participating

The training will require your son/daughter to run fast and exert force for distances up to and including 30metres. Therefore if by any chance you feel that they may be at risk of injury in any session do not hesitate to withdraw them from the session. The sessions aim to complement training that your child will be doing in their individualised sports. The surface will be a grass track at ##### in an aim to minimise shock on the body of the athletes. A thorough warm up, warm down and stretch will be incorporated into the training.

Confidentiality of Information

All of the results obtained and the records of the participants will be kept strictly confidential. The research team are the only people who will have access to your child's files. If you wish, the results of your child's tests will be explained to you privately. All of your child's data will be stored under a code allocated to your child. Only the consent form will contain your child's name and this will be stored separately to the research data. All of the data will be stored for five years after the completion of the study. If your test results are reported at a scientific meeting or published in a research journal, your child's name will not be used.

Participation Criteria

In order to participate in this research project, we need you to meet certain criteria, These are:

- a) Your child is in good general health, and know of no reason, medical or other, why you should not allow your child to participate in this study. For example, there should be no restriction on your child's participation in school physical education classes or sporting activities. On the basis of the information that you provide on the health questionnaire, we may ask you additional questions to be sure it is safe for you to participate. If you are unsure please ask the researchers.
- b) Your child must be 12-17yrs of age.
- c) Your child must not be on any medication (drugs) that might affect their ability to safely exercise. If you are not sure about any medication that your child is taking, ask one of the investigators or fill in the name of the medication on the health status questionnaire. This information is for your own safety. If your child is taking any form of medication (drugs) under medical advice please do not stop taking it because

of this testing. If your child starts taking medication after they have indicated their interest in participating, please notify the investigators as soon as possible in case changes in your testing session are necessary.

If you are unsure of any of these criteria, please phone one of the investigators to check.

For your protection

The researchers conducting this project support the principles governing both the ethical conduct of research, and the protection at all times of the interests, comfort and safety of participants. This Research Project Information Statement is given to you for the protection of your son or daughter.

Your signature on the consent form

After agreeing to participate in this study you will be given a 'consent form' which must be completed by a parent or guardian and returned to the research laboratory on the day of testing.

Your signature on the consent form indicates:

1. you have received the Research Project Information Sheet
2. you have read its contents
3. you have been given the opportunity to discuss the contents with one of the researchers and all questions have been answered to your satisfaction
4. you clearly understand the test procedures and possible risks or discomfort
5. you know of no reason why your son/daughter should not participate
6. your son/daughter voluntarily agrees to participate in the project
7. you may change your mind about your son/daughter's participation at any time

Complaints

It is the policy of the University that if participants have any complaint concerning the manner in which a research project is conducted it may be given to the researcher, Dr Robin Callister, or if an independent person is preferred, to:

The Secretary

Human Research Ethics Committee

Research Branch, Chancellery

University of Newcastle, 2308 Telephone 49216333

Research Project Participant's Consent Form

(To be retained by the researcher)

Project Title: Training for improvement in running speed

Research Supervisor: Dr Robin Callister

Research Student: Mr Cale Wallace

Acknowledgement

I, and my parent guardian, have read the research Project Information Statement and agree to participate in this research project. A copy of the Research Project information statement has been given to myself and my parent guardian to keep. The reason why this experiment is to be undertaken and the exact nature of each of the tests that will be carried out have been fully explained to myself and my parent/guardian. I understand that I may ask questions or withdraw from this project at any time, without any form of penalty or ill will.

Participants Signature

Date

Parent/Guardian's Signature

Date

Signature of Person Presenting This Form

Date

Appendix B

Data

Raw Data – Sprint times for each 10 metre interval (seconds) continued

D1	F	S&B	15.3	16	2	3.49	4.88	2.02	3.5	4.93	1.99	3.43	4.97	2.01	3.45	4.97	1.9	3.34	4.68	1.94	3.38	4.73
D2	B	Speed	15.3	16							1.87	3.22	4.44	1.87	3.21	4.46						
D3	B	S&B	14.9	16	2.01	3.48	4.79	2	3.45	4.75	2.2	3.61	5	2.17	3.7	5	1.95	3.34	4.78	1.9	3.45	4.7
D4	F	Fitness	16.4	Open	2.2	3.67	5	2.18	3.7	5.08	2.1	3.46	4.65	2.15	3.53	4.87	2	3.39	4.7	2	3.48	4.87
D5	B	S&B	15.6	16	2	3.31	4.6				1.86	3.26	4.54	1.87	3.23	4.48						
D6	B	S&B	16	Open																		
D7	B	S&B	15.3	16	1.98	3.35	4.61	2	3.35	4.61	1.96	3.32	4.57	2	3.38	4.67	1.95	3.32	4.52	1.95	3.34	4.57
D8	B	S&B	15.4	16	1.9	3.15	4.35	1.91	3.15	4.36	1.85	3.12	4.32	1.86	3.11	4.31	1.84	3.1	4.3	1.85	3.11	4.29
D9	B	S&B	15.4	16	1.87	3.12	4.26	1.87	3.14	4.3	1.81	3.08	4.23	1.8	3.1	4.25	1.81	3.08	4.27	1.8	3.09	4.26
D10	B	Speed	17.1	Open							1.91	3.28	4.54	1.96	3.36	4.42						
E1	F	S&B	15.6	16	2	3.39	4.75	1.98	3.38	4.77	2.07	3.43	4.78	2.11	3.45	4.76	1.97	3.32	4.62	1.9	3.24	4.59
E2	F	S&B	16.2	Open	2.1	3.57	4.88	2.08	3.55	4.85	2.06	3.45	4.79	2.16	3.59	4.93	2.05	3.45	4.76	2.05	3.39	4.72
E3	B	S&B	15.8	16							1.87	3.18	4.43	1.87	3.18	4.43						
E4	F	Fitness	15.9	16													1.86	3.22	4.47	1.89	3.28	4.44
E5	B	Speed	16.5	Open							1.9	3.2	4.45	1.96	3.25	4.5						
E6	F	S&B	16	Open	2.45	3.88	5.27	2.39	3.85	5.25	2	3.5	4.93	2.05	3.55	4.97	2.1	3.5	4.91	2	3.45	4.8
E7	F	Fitness	15.6	16	2	3.44	4.83	2.04	3.5	4.89	2.05	3.54	4.89	2.1	3.65	5	2.02	3.48	4.85	2.05	3.5	4.91
E8	F	Speed	15.9	16	2	3.45	4.84	2	3.46	4.87	2	3.48	4.9	2.04	3.5	4.88	2.02	3.47	4.84	2.01	3.51	4.53
E9	F	S&B	16.9	Open	2.15	3.58	4.92	2.17	3.6	5	2	3.4	4.7	2.05	3.45	4.8	2	3.45	4.8	2.05	3.5	4.91
E10	B	Speed	16.4	Open	1.75	3.06	4.3	1.93	3.22	4.44	1.82	3.13	4.4	1.82	3.18	4.44	1.81	3.12	4.38	1.82	3.15	4.45
F1	F	Speed	17.8	Open	2.11	3.45	4.7				1.9	3.27	4.53	1.9	3.3	4.65						
F2	F	Speed	16.3	Open	1.86	3.22	4.52	1.87	3.23	4.51	1.85	3.29	4.4	1.9	3.34	4.5	1.84	3.25	4.42	1.86	3.23	4.4
F3	F	Fitness	17.5	Open							2.19	3.48	4.69	2.11	3.35	4.56						
F4	B	Speed	16.7	Open	1.86	3.21	4.46	1.87	3.21	4.46	1.82	3.32	4.34	1.85	3.3	4.4	1.81	3.3	4.38	1.85	3.36	4.46
F5	F	Speed	17.6	Open																		
F6	F	Speed	16.4	Open																		
F7	B	Fitness	16.3	Open	1.88	3.2	4.55	1.89	3.19	4.54	1.86	3.17	4.42	1.87	3.17	4.44	1.86	3.18	4.41	1.84	3.2	4.41
F8	B	Speed	16.4	Open																		
F9	B	Speed	16.7	Open	2.01	3.4	4.63	2	3.4	4.61	1.99	3.41	4.6	1.98	3.4	4.59	1.97	3.41	4.59	2	3.45	4.63
F10	B	S&B	17.4	Open	2.2	3.67	4.9	2.16	3.63	4.85	2.14	3.65	4.88	2.12	3.69	4.9	2.1	3.49	4.84	2.15	3.47	4.84

Raw Data- Bounds distance 10 bounds (metres)

Name	B/F	Group	Age	Team	Trial 1		Trial 2		Trial 3	
A1	B	Fitness	13.2	14	21.9	22	22.9	23.3	23.4	23.5
A2	B	Speed	13.4	14						
A3	F	Speed	12.7	14	16.4	16.8	17.8	16.9	18	17.9
A4	F	S&B	13	14	19.9	20	20.8	21.4	21.3	21.4
A5	B	Speed	11.9	14	19.8	19.6	17.8	19.9	19.8	20
A6	B	S&B	12.5	14	15.1	15.5	16.2	18.1	17.5	18.1
A7	F	S&B	13.2	14	17.5	17.9	18.5	18.2	19.8	20
A8	B	S&B	12.4	14	16.9	17.4	19.4	19.4	19.3	20.3
A9	F	Speed	13.7	14	19.2	19.8	22	21.2	21	21.4
A10	B	Fitness	14.7	16	21.8	22.4	24.3	22.4	22.4	22.6
B1	B	Fitness	13.6	14			21	21.2	21	21.6
B2	F	Fitness	13.1	14	20.9	20.8	19.5	22.7	23.2	21.6
B3	F	Fitness	13.7	14	19.4	19.6			21.2	21
B4	F	Fitness	13.8	14	19.9	20	19.8	21.4	22.8	23.6
B5	F	S&B	13.1	14	18.8	19.4	19.8	19.7	21.2	20.6
B6	F	S&B	13.1	14	19.7	20.1	20.5	20.6	22.2	22
B7	F	Speed	13.1	14	22.8	22.6			23	23
B8	B	Fitness	14.3	16	19.9	21.2	20.5	20.4	21.8	21.6
B9	F	Fitness	14.5	16	19.5	19.6	19.5	19.3	21.3	21.4
B10	B	Speed	14.8	16	23.1	23.4	23.7	24.7	24.4	23.4
C1	F	S&B	14.7	16	18	18.5	20.4	19.7	20.4	20.6
C2	B	Speed	14.2	16	22.2	23	24.2	24.1	24.2	24.2
C3	F	S&B	14.2	16	21.7	21.8	21.7	22	23	22.8
C4	F	Fitness	14.6	16			22.5	22.8		
C5	F	Fitness	14.7	16	19.8	20	20.9	20.9	20.7	20.8
C6	F	Speed	14.7	16	16.3	16.7	18.3	18.7	21.1	20.5
C7	B	Fitness	14.6	16	17.6	18	19	19.4	20.3	18.8
C8	B	Fitness	16.4	Open					21.4	21.3
C9	F	S&B	15.1	16	18.8					
C10	F	Speed	15.8	16	20.1					

Raw Data- Bounds distance 10 bounds (metres) continued

D1	F	S&B	15.3	16	20.6	20.4	19.4	19.8	20.8	20.3
D2	B	Speed	15.3	16			24.3	25.1		
D3	B	S&B	14.9	16	20.1	20.5	21.3	22.4	22.3	19
D4	F	Fitness	16.4	Open	19.4	19.5	20.4	20.6		
D5	B	S&B	15.6	16	21.9	22	21.9	22.5		
D6	B	S&B	16	Open						
D7	B	S&B	15.3	16	23	23.5	24.9	25	26.6	26.6
D8	B	S&B	15.4	16	24.2	24.8	25.9	26.1	26.2	26.5
D9	B	S&B	15.4	16	23.6	23.9	24.2	24	25.1	25.4
D10	B	Speed	17.1	Open						
E1	F	S&B	15.6	16	19.1	19.5	21.6	22.5	23.1	22.9
E2	F	S&B	16.2	Open	21.9					
E3	B	S&B	15.8	16			24.4	24.8		
E4	F	Fitness	15.9	16					23.3	23.4
E5	B	Speed	16.5	Open						
E6	F	S&B	16	Open	19.4	20	21.7	21.9	23	23.2
E7	F	Fitness	15.6	16	22	22.1	20.4	20.3	22.1	22.2
E8	F	Speed	15.9	16	19.4	19.6	20.2	19.8	21	20.8
E9	F	S&B	16.9	Open	20.3	20.4	21.6	21.4	22	21.8
E10	B	Speed	16.4	Open	21.2	22	22.5	22.6	22.8	22.8
F1	F	Speed	17.8	Open	21.9					
F2	F	Speed	16.3	Open	22.6	22.8	23	23.2	23.2	23.4
F3	F	Fitness	17.5	Open						
F4	B	Speed	16.7	Open	20.8	21	22	22.1	22.3	22.9
F5	F	Speed	17.6	Open						
F6	F	Speed	16.4	Open						
F7	B	Fitness	16.3	Open	22.8	23	23.1	23.4	23.8	23.6
F8	B	Speed	16.4	Open						
F9	B	Speed	16.7	Open	22.4	22.6	23	23.9	24.8	24.6
F10	B	S&B	17.4	Open						

Bibliography

- Adams, T. M., Worley, D. and Throgmartin. (1987). "The effects of selected plyometric weight training on muscular leg power." Track and Field Quarterly Review **87**(4): 45-47.
- Aldridge, J. (1993). The effect of injuries on growth. In: Coaching children in sport - principles and practice. Lee, M. (eds) London, Chapman & Hall.
- Almarwaey, O. A., Jones, A.M. and Tolfrey, K. (2004). "Maximal lactate steady state in trained adolescent runners." Journal of Sports Sciences **22**: 215-225.
- Almasbakk, B. and J. Hoff (1996). "Coordination the determinant of velocity specificity." Journal of Applied Physiology. **80**: 2046-52.
- Australian Strength & Conditioning Association (2006). Australian Strength & Conditioning Association Level II Coaching Course Manual.
- Astrand, P. O. (1976). The child in sport and physical activity: physiology. In: Child in Sport and Physical Activity. J.B. Albinson and G. M. Andrew. Baltimore, University Park Press: 19-33.
- Astrand, P. O., L. Engstrom, B. Eriksson, P. Karlberg, I. Nylander, B. Saltin, and C. Thoren. (1963). "Girl swimmers." Acta Paediatrica **supplement**: 147.
- Baker, D. (1999). "A comparison of running speed and quickness between elite professional and young rugby league players." Strength and Conditioning Coach **7**: 3-7.
- Baker, D. and S. Nance (1999). "The relationship between running speed and measures of strength and power in professional rugby league players." Journal of Strength and Conditioning Research **13**: 230-235.
- Bale, P., Mayhew, J.L., Piper, F.C., Ball, T.E., and Willman, M.K. (1992). "Biological and performance variables in relation to age in male and female adolescent athletes." The Journal of Sports Medicine and Physical Fitness.
- Ballreich, R. (1975). A model for estimating the influence of stride length and stride frequency on the time in sprinting events. Proceedings of the VIth International Congress on Biomechanics, Jyvaskyla, Finland.
- Bar-Or, O. (1983). Pediatric sports medicine for the practitioner: from physiologic principles to clinical applications. New York, Springer-Verlag.
- Bar-Or, O. (1986). "Physiologic differences in response to exercise between children and adults." In: Welsh, P. and R.J. Shephard (eds) Current Therapy in Sports Medicine. Philadelphia, Decker Inc. pp125-127.

Bar-Or, O., R. Dotan, A. Rotstein, and J. Karlsson (1980). "Anaerobic capacity and muscle fibre type distribution in man." International Journal of Sports Medicine **1**: 82-85.

Bar-Or, O. and L. Zwiren (1973). Physiological effects of frequency and content variation of physical education classes and of endurance conditioning on 9-10 year old boys and girls. In: Pediatric Work Physiology: Proceedings of 4th International Symposium. O. Bar-Or. Israel, Wingate Institute: pp198-208.

Batterham, A. and W. Hopkins (2006). "Making meaningful inferences about magnitudes." International Journal of Sports Physiology and Performance **1**(1): 50-7.

Beneke, R., Heck, H., Schwarz, V., and Leithauser, R. (1996). "Maximal lactate steady state during the second decade of age." Medicine & Science in Sports & Exercise **28**(12): 1474-8.

Bennett, S. (2003). "Teaching children to run fast." Modern Athlete & Coach **41**(4): 20-22.

Beznak, M. (1960). "The role of anterior pituitary hormones in controlling size, work and strength of the heart." Journal of Physiology, London **150**: 251-265.

Biddle, S. (1993). How children see success and failure. In: Coaching children in sport - principles and practice. Lee, M. (eds) London, Chapman & Hall.

Bishop, D. and M. Spencer (2004). "Determinants of repeated-sprint ability in well trained team-sport athletes and endurance-trained athletes." Journal of Sports Medicine and Physical Fitness **44**(1): 1-7.

Blattner, S. E. and L. Noble (1979). "Relative effects of isokinetic and plyometric training on vertical jumping performances." Research Quarterly for Exercise and Sport **50**: 583-588.

Blazevich, A. J., Jenkins, D. (1997). "Physical performance differences between weight-trained sprinters and weight trainers." Journal of Science and Medicine in Sport **1**(1).

Bloxham, S. R., Welshman, J.R., & Armstrong, N. (2005). "Ergometer-Specific Relationships Between Peak Oxygen Uptake and Short-Term Power Output in Children." Pediatric Exercise Science **17**: 136-148.

Boisseau, N. and P. Delamarche (2000). "Metabolic and Hormonal Responses to Exercise in Children and Adolescents." Sports Medicine **30**(6): 405-422.

Borms, J. (1986). "The child and exercise: an overview." Journal of Sports Science **4**: 3-20.

Bosco, C., & Vittori, C. (1986). "Biomechanical Characteristics of Sprint Running During Maximal and Supra-Maximal Speed." New Studies in Athletics **1**: 39-45.

- Branda, C., J. Haubenstricker, and J. Seefeldt. (1984). "Age changes in motor skills during childhood and adolescence." Exercise Sports Science Review **12**: 467-520.
- Brown, E., W. Lillegard, R. Henderson, D. Wilson, E. Lewis, D. Hough, and K. Stringer. (1992). "Efficacy and safety of strength training with free weights in prepubescents to early post-pubesents." Medicine and Science in Sports and Exercise **24 supplement**: 82.
- Brown, M. E., Mayhew, J.L. and Boleach, L.W. (1986). "Effect of plyometric training on vertical jumping performance in high school basketball players." Journal of Sports Medicine and Physical Fitness **26**: 1-4.
- Burdukiewicz, A. and A. Janusz (1995). "Physical capacity and fitness of children and youths as related to their somatic development." Biology of Sport **12**(3): 175-188.
- Callister, R., Shealy, M.J., Fleck, S.J. and Dudley, G. (1988). "Performance adaptations to sprint, endurance and both modes of training." Journal of Applied Sports Science Research **2**(3): 46-51.
- Caruso, C. and D. Gill (1992). "Strengthening physical self-perceptions through exercise." The Journal of Sports Medicine and Physical Fitness **32**(4): 416-427.
- Cavagna, G. A., Komarek, L. and Mazzoleni, S. (1971). "The mechanics of sprint running." Journal of Physiology **217**: 709-721.
- Chelly, S. M. and Denis, C. (2001). "Leg power and hopping stiffness: relationship with sprint running performance." Medicine & Science in Sports & Exercise **33**(2): 326-333.
- Christou, M., Smilios, I., Sotiropoulos, K., Volaklis, K., Piliandis, T. and Tokmakidis, S.P. (2006). "Effects of resistance training on the physical capacities of adolescent soccer players." Journal of Strength and Conditioning Research **20**(4): 783-791.
- Chu, D. (1998). Jumping Into Plyometrics. Boston, USA, Human Kinetics.
- Chu, D. and R. Korchemy (1993). "Sprinting Stride Actions: Analysis and Evaluation." National Strength and Conditioning Association Journal **15**(1): 48-53.
- Clark, L. (2006). Anthropometric and physical fitness characteristics of rugby league players by grade and position. Master Medical Science Faculty of Health, University of Newcastle Unpublished Thesis.
- Clutch, D., Wilton, M., McGown, C. and Bryce, G.R. (1983). "The effect of depth jumping and weight training on leg strength and vertical jump." Research Quarterly for Exercise and Sport **54**: 5-10.
- Crasselt, W., Forchel, I and Stemmler, R. (1985). "Zur körperlichen Entwicklung der Schuljugend in der Deutschen Demokratischen Republik." Sportmedizinische Schriftenreihe **23**.

- Cronin, J., and Sleivert, G. (2005). "Challenges in Understanding the Influence of Maximal Power Training on Improving Athletic Performance." Sports Medicine **35**(3): 213-234.
- Cronin, J. and K. Hansen (2006). "Resisted sprint training for the acceleration phase of sprinting." National Strength and Conditioning Association Journal **28**(4): 42-51.
- Cronin, J. B., McNair, P.J. and Marshall, R.N. (2000). "The role of maximal strength and load on initial power production." Medicine and Science in Sports and Exercise: 1763-1769.
- Daly, R. M., Bass, S., Caine, D., and Howe, W. (2002). "Does training affect growth?" The Physician and Sportsmedicine **30**(10): 21-29.
- Daniels, J. and N. Oldridge (1971). "Changes in oxygen consumption of young boys during growth and running training." Medicine and Science in Sports and Exercise **3**: 161-165.
- Daniels, J., Oldridge, N., Nagle, F., and White, B. (1978). "Differences and changes in VO₂ among young runners 10-18 years of age." Medicine and Science in Sports and Exercise **10**(3): 200-203.
- Dawson, B., Fitzsimmons, M., Green, S., Goodman, C., Carey, M., Cole, K. (1993). "Changes in performance, muscle metabolites, enzymes and fibre types after short sprint training." European Journal of Applied Physiology and Occupational Physiology **78**(2): 163-169.
- Debnam, M. (2007). "Plyometrics: training for power." Modern Athlete and Coach **45**(4): 5-7.
- Delecluse, C. (1997). "Influence of strength training on sprint running performance. Current findings and implications for training." Sports Medicine **24**: 147-156.
- Diallo, O., Dore, E. Hautier, C., Duche, P. and Van Praagh, E. (1999). "Effects of jump and sprint training on athletic performance in prepubescent boys." Medicine and Science in Sports and Exercise **31 supplement**: 1581.
- Diallo, O., Dore, E., Duche, P. and Van Praagh, E. (2001). "Effects of plyometric training followed by a reduced training program on physical performance in prepubescent soccer players." Journal of Sports Medicine and Physical Fitness **41**: 342-348.
- Dick, F. (1987). "Developing Sprinting Speed." Athletics Coach (London) **21**(4): 4-5.
- Dick, F. (1996). "No Speed Limits." New Studies in Athletics **11**(2): 23-27.
- Dick, F. (2003). Sports Training Principles. London, A & C Black.
- Docherty, D., Wenger H.A. and Neary P. (1988). "Time motion analysis related to the physiological demands of rugby." Journal of Human Movement Studies **14**: 269-277.

- Docherty, D. W., H. & Collis, M. (1987). "The effects of resistance training on aerobic and anaerobic power of young boys." Medicine and Science in Sports and Exercise **19**: 389-392.
- Donati, A. (1996). "The association between the development of strength and speed." New Studies in Athletics **11**(2): 51-58.
- Ekblom, B. (1969). "Effect of physical training on adolescent boys." Journal of Applied Physiology **27**: 350-359.
- Eriksson, B. O. (1972). "Physical Training, oxygen supply and muscle metabolism in 11 to 15 year old boys." Acta Physiologica Scandinavia supplement: **384**: 1-48.
- Faigenbaum, A., L. D. Zaichkowsky, Westcott, W.L., Micheli, L.J., and Fehlandt, A.F. (1993). "The effects of a twice-a-week strength training program on children." Paediatric Exercise Science **5**: 339-346.
- Faigenbaum, A. D. (1993). "Strength Training: A Guide For Teachers and Coaches." National Strength and Conditioning Association Journal **15**(5): 20-29.
- Faigenbaum, A. D., LaRossa Loud R., O'Connell, J., Glover, S., Westcott, W.L. (2001). "Effects of different resistance training protocols on upper-body strength and endurance development in children." Journal of Strength and Conditioning Research: 459-465.
- Faigenbaum, A. D., Milliken, L., Moulton, L. & Westcott, W.L. (2005). "Early Muscular Fitness Adaptations in Children in Response to Two Different Resistance Training Regimens." Pediatric Exercise Science **17**: 237-248.
- Faigenbaum, A. D., Milliken, L.A., Laraossa Loud, R., Burak, B.T., Doherty, C.L., Westcott, W.L. (2002). "Comparison of 1 and 2 days per week of strength training in children." Research Quarterly for Exercise and Sport **73**(4): 416-424.
- Faigenbaum, A. D., O'Connell, J., La Rosa, R., & Westcott, W. (1999). "Effects of strength training and complex training on upper body strength and endurance development in children." Journal of Strength and Conditioning Research **13**: 424-427.
- Faigenbaum, A. D., Westcott, W.L., Micheli, L.J., Outerbridge, A.R., Long, C.J., LaRossa-Loud, R., Zaichkowsky, L.D. (1996). "The effects of strength training and detraining on children." Journal of Strength and Conditioning Research **10**(2): 109-114.
- Falgairrette, G., Bedu, M., Fellman, N., Van Praagh, E. and Coudert, J. (1991). "Bioenergetic profile in 144 boys aged from 6-15years with special reference to sexual maturation." European Journal of Applied Physiology **62**: 151-156.
- Falgairrette, G., Bedu, M., Fellman, N., Van Praagh, E., Jarrige, J., and Coudert, J. (1991). "Modifications of aerobic and anaerobic metabolisms in active boys during puberty." European Journal of Applied Physiology **62**: 42-50.

- Falk, B. and R. Dotan (2006). "Child-Adult differences in the recovery from high-intensity exercise." Exercise Sports Science Review **34**(3): 107-112.
- Farley, C. T., Blickhan, R., Saito, J. and Taylor, C.R. (1991). "Hopping frequency in humans: a test of how springs set stride frequency in bouncing gaits." Journal of Applied Physiology **71**: 2127-2132.
- Ferretti, G., Narici, M.V., Binzoni, T., Gariod, L., Le Bas, J.F., Reutenauer, H. and Cerretelli, P. (1994). "Determinants of peak muscle power: effects of age and physical conditioning." European Journal of Applied Physiology **68**: 111-115.
- Fitzsimmons, M., Dawson, B., Ward, D. and Wilkinson, A. (1993). "Cycling and Running Tests of Repeat Sprint Ability." The Australian Journal of Science and Medicine in Sport: 82-88.
- Ford, H. T., Puckett, J.R., Drummond, J.P., Sawyer, K., Gantt, K. and Fussell, C. (1983). "Effects of three combinations of plyometric weight training programs on selected physical fitness test items." Perceptual Motor Skills **56**: 919-922.
- Fournier, M., Ricci, J., Taylor, A.W., Ferguson, R.J. and Montpetit, R.R. (1982). "Skeletal muscle adaptation in adolescent boys; sprint and endurance training and detraining." Medicine and Science in Sports and Exercise **14**: 453-456.
- Francis, C. (1997). Training for Speed. Australia, Union Offset & Co.
- Gabbett, T. (2006). "A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players." Journal of Sports Sciences **24**(12): 1273-1280.
- Gajer, B., Thepaut-Mathieu, C., & Lehenaff, D. Evolution of stride and amplitude during course of the 100 m event in athletics. (1999). "Evolution of stride and amplitude during course of the 100 m event in athletics." New Studies in Athletics, Aachen **14**(1): 43-50.
- Gambetta, V. (1996). "How to Develop Sport-Specific Speed." Sports Coach **19**(3).
- Gambetta, V. (1996). "Leaps and Bounds." Sports Coach **18**(4): 14-18.
- Gatch, W. and R. Byrd (1979). "Endurance training and cardiovascular function in 9 and 10 year old boys." Archives of Physical Medicine and Rehabilitation **60**: 574-577.
- Giles, K. (2007). "Developing physical competence: the cornerstone of long term athletic development (LTAD)." Modern Athlete and Coach **45**(1): 8-12.
- Gillam, G. (1985). "Identification of anthropometric and physiological characteristics relative to participation in college basketball players." National Strength and Conditioning Association Journal **7**: 34-36.

- Gilliam, T. B. and P. S. Freedson (1980). "Effects of a 12-week school physical fitness program on peak VO₂, body composition and blood lipids in 7-9 year old children." International Journal of Sports Medicine **1**(2): 73-78.
- Hakkinen, K. (1989). "Neuromuscular and hormonal adaptations during strength and power training." Journal of Sports Medicine & Physical Fitness **29**(1): 9-25.
- Hakkinen, K. and L. Keskinen (1989). "Muscle cross-sectional area and voluntary force production characteristics in elite strength-endurance trained athletes and sprinters." European Journal of Applied Physiology **59**: 215-220.
- Hakkinen, K., Komi, P.V. and Alen, M. (1985). "Effective explosive type strength training on isometric force and relaxation time, electromyographic and muscle fibre characteristics of leg extensor muscles." Acta Physiologica Scandinavia **125**: 587-600.
- Hakkinen, K., Komi, P.V., and Alen, M. (1989). "Effect of explosive type strength training on isometric force and relaxation time, electromyographic and muscle fibre characteristics of leg extensor muscles." Acta Physiologica Scandinavia **125**: 587-600.
- Harris, N., Cronin, J., & Keogh, J. (2007). "Contraction force specificity and its relationship to functional performance." Journal of Sports Sciences **25**(2): 201-212.
- Hetzler, R. K., DeRenne, C., Buxton, B.P., Ho, K.W., Chai, D.X., & Seichi, G. (1997). "Effects of 12 weeks of strength training on anaerobic power in prepubescent male athletes." Journal of Strength and Conditioning Research **11**: 174-181.
- Hollman, W. and T. Hettinger (1976). "Arbeitsund Trainingsgrundlagen." Sportsmedizin.
- Ikai, M. (1964). The effects of training on muscle endurance. Proceedings of International Congress of Sports Sciences, Tokyo, University of Tokyo Press.
- Inbar, O. and O.Bar-Or. (1983). "Anaerobic characteristics in male children and adolescents." Medicine and Science in Sports and Exercise **18**: 264-269.
- Ingle, L., Sleaf, M. & Tolfrey, K. (2006). "The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys." Journal of Sports Sciences **24**(9): 987-997.
- Joch, W. (1990). "Dimensions of Motor Speed." Modern Athlete and Coach **28** (2): 25-29.
- Juzwiak, C.R., Amancio, O.M.S., Vitale, M.S.S., Szejnfeld, V.L. and Pinheiro, M.M. (2008). "Effect of calcium intake, tennis playing, and body composition on bone mineral density of Brazilian male adolescents." International Journal of Sport Nutrition and Exercise Metabolism **18**: 524-538.
- Klissouras, V. (1971). "Heritability of adaptive variation." Journal of Applied Physiology **31**: 338-344.

- Kobayashi, K., Kitamura, K., Miura, M., Sodeyama, H., Murase, Y., Miyashita, M. & Matsui, H. (1978). "Aerobic power as related to body growth and training in Japanese boys: a longitudinal study." Journal of Applied Physiology **44**(5): 666-672.
- Koch, G. and B. O. Eriksson (1973). "Effect of physical training on pulmonary ventilation and gas exchange during sub-maximal and maximal work in boys aged 11-13 years." Journal of Clinical Laboratory Investigations **31**: 87-94.
- Komi, P. (1986). "Training of muscle strength and power: interaction of neuro motoric, hypertrophic, and mechanical factors." International Journal of Sports Medicine **7**: 10-15.
- Korchemny, R. (1992). "A new concept for sprint start and acceleration training." New Studies in Athletics, Monaco **7**(4).
- Kotzamanidis, C. (2003). "The effect of sprint training on running performance and vertical jumping in preadolescent boys." Journal of Human Movement Studies **44**: 225-240.
- Kotzamanidis, C. (2006). "Effect of Plyometric Training on Running Performance and Vertical Jumping in Prepubertal Boys." Journal of Strength and Conditioning Research **20**(2): 441-445.
- Kotzamanidis, C., Chatzopoulos, D., Michailidis, C., Papaiakovou, G. and Patikas, D. (2005). "The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players." Journal of Strength and Conditioning Research **19**(2).
- Kozlov, I. and V. Murayev (1992). "Muscles and the sprint." Fitness and Sports Review International: 192-195.
- Krahenbuhl, G. S., J S. Skinner and W.M. Kohrt. (1985). Developmental aspects of maximal aerobic power in children. Exercise Sport Science Reviews. R. L. Terjung. New York, Macmillan. **13**: 503-538.
- Kristensen, G. O., Van der Tillaar, R., Ettema, Gertjan, J.C. (2006). "Velocity specificity in early-phase sprint training." Journal of Strength and Conditioning Research **20**(4).
- Kubo, K., Kanehisa, H., Kawakami, Y. and Fukunaga, T. (2000). "Elasticity of tendon structures of the lower limbs in sprinters." Acta Physiologica Scandinavia **168**: 327-335.
- Kukolj, M., Ropret, R., Ugarkovic, D., and S. Jaric. (1999). "Anthropometric, strength, and power predictors of sprinting performance." Journal of Sports Medicine and Physical Fitness **39**: 120-122.
- Kutsar, K. (1990). "Hereditary prerequisites in the selection of potential talent." Modern Athlete and Coach **29**: 12-14.

- Kyrolainen, H., Komi, P.V., Belli, A. (1999). "Changes in muscle activity patterns and kinetics with increasing running speed." Journal of Strength and Conditioning Research **13**(4): 400-6.
- Lee, M. (1993). Growing up in sport. In: Coaching children in sport - principles and practice. Lee, M. (eds) London, Chapman & Hall.
- LeMura, L. M., Von Dullivard, S.P., & Carlonas, R. (1999). "Can Exercise Training Improve Maximal Aerobic Power (VO₂Max) in Children: A Meta-Analytic Review." Journal of Exercise Physiology Online **2**(3).
- Letzelter, M. (1978). "Trainingsgrundlagen." Rowohlt Taschenbuch Verlag GmbH Reinbek bei Hamburg.
- Locatelli, E. (1996). "The importance of anaerobic glycolysis and stiffness in the sprints (60, 100 and 200 metres)." New Studies in Athletics, Monaco **11**(2): 121-125.
- Lundin, P. and W. Berg (1991). "A review of plyometric training." National Strength and Conditioning Association Journal **13**(6): 22-31.
- Lussier, L. and E. R. Buskirk (1977). "Effects of an endurance training regimen on assessment of work capacity in prepubertal children." Annals of New York Academy of Science **301**: 734-747.
- MacKelvie, K.J., Khan, K.M. and McKay, A.H. (2002). "Is there a critical period for bone response to weight-bearing exercise in children and adolescents? A systematic review." British Journal of Sports Medicine **36**(4): 250-257; discussion 257.
- Malina, R. and G. Beunen (1988). "Growth and Physical Performance Relative to the Timing of the Adolescent Growth Spurt." Exercise Sports Science Reviews **16**: 503-540.
- Malina, R. M. (1988). Growth and maturation of young athletes: biological and social considerations. In: Children in sport. F. L. Smoll. Champaign, Illinois, Human Kinetics: 83-101.
- Malina, R. M. (1990). Tracking of physical fitness and performance during growth. Children and exercise. G. Beunen. Stuttgart, Ferdinand Enke Verlag: 1-10.
- Malina, R. M. (1993). Youth in competitive sport at elite levels. Proceedings of international sports science conference. "Optimising Performance". Singapore.
- Malina, R. M. (1994). "Physical Activity and training: effects on stature and the adolescent growth spurt." Medicine and Science in Sports and Exercise.
- Malina, R. M. (1994). "Physical activity and training: effects on stature and the adolescent growth spurt." Medicine and Science in Sports and Exercise: 759-766.

Malina, R. M. (1996). The young athlete: biological growth and maturation in a biocultural context. In: Children and youth in sport: a biopsychosocial perspective. F. L. Smoll. Madison, Wisconsin, Brown & Benchmark: 161-186.

Malina, R. M. (2006). "Youth Physical Activity: Implications for Adult Physical Activity and Health." Studies in Physical Culture and Tourism **13**. 29-33.

Malina, R. M., & Bielicki, T., Growth and Maturation of Boys Active in Sports: Longitudinal Observations from the Wroclaw Study (1994). "Growth and Maturation of Boys Active in Sports: Longitudinal Observations from the Wroclaw Study." Paediatric Exercise Science **4**(1): 68-77.

Malina, R. M., Bouchard, C., and Bar-Or, O. (2004). Growth, Maturation and Physical Activity. USA, Human Kinetics.

Mann, R. (1985). Biomechanical analysis of the elite sprinter and hurdler. The Elite Athlete, Spectrum Publications: 43-80.

Mann, R. V. and P. Sprague (1983). "Kinetics of Sprinting." Track and Field Quarterly Review: 4-9.

Margaria, R., Aghemo, P. and Rovelli, E. (1966). "Measurement of muscular power (anaerobic) in man." Journal of Applied Physiology **21**: 1662-1664.

Massicotte, D. and R. MacNab (1974). "Cardiorespiratory adaptations to training at specified intensities in children." Medicine and Science in Sports and Exercise **6**: 242-246.

Matavulj, D., Kukolj, M., Ugarkovic, D., Tihanyi, J., and Jaric, S. (2001). "Effects of plyometric training on jumping performance in junior basketball players." Journal of Sports Medicine and Physical Fitness **41**: 159-164.

Mcardle, W. D., F. I. Katch, V.L. Katch. (1991). Exercise Physiology: Energy, Nutrition, and Human Performance, Lea & Febiger, Boston.

Medlicott, R. (2006). "Medium to Long Term Development of Strength and Power in Developing Sprinters." Modern Athlete and Coach **44**(1).

Meir, R., R. Newton, E. Curtis, M. Fardell, and B. Butler. (2001). "Physical fitness qualities of professional rugby league football players: determination of positional differences." Journal of Strength & Conditioning Research **15**(4): 450-458.

Mero, A. (1985). "Relationships between the muscle fibre characteristics, sprinting and jumping of sprinters." Biology of Sport **2**: 155-161.

Mero, A. (1988). "Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting." Research Quarterly for Exercise and Sport **59**: 94-98.

Mero, A. (1992). "Skeletal muscle fibre characteristics and anaerobic work in pubertal boys during training." Medicine and Science in Sports and Exercise **24 supplement**: 82.

Mero, A. (1993). "Neuromuscular performance and skeletal muscle fibre characteristics in pubertal power athletes during training." Medicine and Science in Sports and Exercise **25 supplement**: 47.

Mero, A. (1998). Power and speed training during childhood. Pediatric Anaerobic Performance. E. V. Praagh. Champaign, Illinois, Human Kinetics: 241-267.

Mero, A., L. Jaakola, and P.V. Komi. (1991). "Relationships between muscle fibre characteristics and physical performance capacity in trained athletic boys." Journal of Sports Sciences **9**: 161-171.

Mero, A., Kauhanen, H., Peltola, E., & Vuorimaa, T. (1988). "Changes in endurance, strength and speed capacity of different prepubescent athletic groups during one year of training." Journal of Human Movement Studies **14**: 219-239.

Mero, A., Kauhanen, H., Peltola, E., Vuorimaa, T., Komi, P.V. (1990). "Physiological performance capacity in different prepubescent athletic groups." Journal of Sports Medicine and Physical Fitness **30**(1): 57-66.

Mero, A. and P. V. Komi (1994). "EMG, force, and power analysis of sprint-specific strength exercises." Journal of Applied Biomechanics **10**: 1-13.

Mero, A., Komi, P.V., and Gregor, R.J. (1992). "Biomechanics of sprint running: A review." Sports Medicine **13**: 376-392.

Mero, A., Lehtimäki, M., Mäkelä, J., Levola, M., Helander, E., Rajala, T., Aura, O., Peltola, E., Joutte, P., and Pullinen, T. (1992). "Performance capacity of young speed and speed-strength athletes during two years of training." Sprint Hurdle Journal **3-4**: 20-33.

Mero, A., Luhtanen, P., Viitasalo, J.T., and Komi, P.V. (1981). "Relationships between the maximal running velocity, muscle fibre characteristics, force production and force relaxation of sprinters." Scandinavia Journal of Sports Science **3**: 16-22.

Mero, A., P Luhtanen, and P.V. Komi. (1983). "A biomechanical study of the sprint start." Scandinavian Journal of Sports Science **5**: 20-28.

Mero, A., Vuorimaa, T., and Hakkinen, K. (1990). Training in children and adolescents. Jyväskylä, Finland, Gummerus Kirjapaino Oy.

Mirwald, R., Bailey, D. Cameron, N. & Rasmussen, R. (1981). "Longitudinal comparison of aerobic power in active and inactive boys aged 7-17 years." Annals of Human Biology **8**: 405-414.

Mocellin, R. and U. Wasmund (1973). Investigations on the influence of a running-training programme on the cardiovascular and motor performance capacity in 53 boys and girls of a second and third primary school class. Pediatric Work Physiology. Proceedings of the Fourth International Symposium. O. Bar-Or. Netanya, Wingate Institute.

Moravec, P., Ruzicka, J., Susanka, P., Dostal, M., Kodejs, M. and Nosek, M. (1988). "The 1987 International Athletic Foundation/IAAF Scientific Project Report: Time analysis of the 100 metres events at the II World Championships in Athletics." New Studies in Athletics **3**(3): 61-96.

Mosher, R. E., Rhodes, E.C., Wenger, H.A. and Filsinger, B. (1985). "Interval training: the effects of a 12-week programme on elite, pre-pubertal male soccer players." Journal of Sports Medicine **25**.

Murphy, A. J., Lockie, R.G, Coutts A.J. (2003). "Kinematic determinants of early acceleration in field sport athletes." Journal of Sports Science and Medicine **2**(4).

Naughton, G., Farpour-Lambert, N.J., Carlson, J., Bradney, M. & Van Praagh, E. (2000). "Physiological Issues Surrounding the Performance of Adolescent Athletes." Sports Medicine **30**(5): 309-325.

Nesser, T. W., Latin, R.W., Berg, K., and Prentice, E. (1996). " Physiological determinants of 40 meter sprint performance in young male athletes." Journal of Strength and Conditioning Research **10**: 263-267.

Newman, M. A., Tarpinning, K.M., & Marino, F.E. (2004). "Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players." Journal of Strength and Conditioning Research **18**(4): 867-872.

Newton, R. and W. Kraemer (1994). "Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy." National Strength and Conditioning Journal **16** (5): 20-31.

O'Connor, D. (1996). "Physiological characteristics of professional rugby league players." Strength and Conditioning Coach **4**: 21-26.

Ondrak, K.S. and Morgan, D.W. (2007). "Physical activity, calcium intake and bone health in children and adolescents." Sports Medicine **37**(7): 587-600.

Ostojic, S. M., Mazic, S., and Dikic, N. (2006). "Profiling in Basketball: Physical and Physiological Characteristics of Elite Players." Journal of Strength and Conditioning Research **20**(4): 740-744.

Palgi, Y., Gutin, B., Young, J., Alejandro, G. (1984). " Physiologic and anthropometric factors underlying endurance performance in children." International Journal of Sports Medicine **5**: 67-73.

Parr, R. B., Wilmore, J.H., Hoover, R., Bachman, D., and Kerlan, R. (1978). "Professional basketball players: Athletic profiles." Sportsmedicine **6**: 77-84.

Pate, R. and Ward, D.S. (1996). Endurance trainability of children and youth. In: The child and adolescent athlete. Bar-Or. O. Oxford, Blackwell Science: 130-7.

Pfeiffer, D. and R. Francis (1986). "Effects of strength training on muscle development in prepubescent, pubescent and post pubescent males." The Physician and Sportsmedicine **14**(9): 134-144.

Plank, D. M., Hipp, M.J., & Mahon, A.D. (2005). "Aerobic Exercise Adaptations in Trained Adolescent Runners Following A Season Of Cross-Country Training." Research in Sports Medicine **13**: 273-286.

Plowman, S. (1989). "Maturation and Exercise Training in Children." Pediatric Exercise Science **1**: 303-312.

Polhemus, R. and E. Burkhardt (1980). "The effects of plyometric training drills on the physical strength gains of collegiate football players." National Strength and Conditioning Association Journal **2**(1): 13-15.

Polhemus, R., Burkhardt, E., Osina, M. and Patterson, M. (1980). "The effects of plyometric training with ankle and vest weights on conventional weight training programs for men." Track and Field Quarterly Review **80**(4): 59-61.

Poole, W. and M. Maneval (1987). "The effects of two ten-week depth jumping routines on vertical jump performance as it relates to leg power." Journal of Swimming Research **3**: 11-14.

Potach, D. (2004). Plyometric and Speed Training. In: NSCA's Essentials of Personal Training. R.W. Earle, T.R. Baechle Champaign, Illinois, Human Kinetics: 425-444.

Potteiger, J., Lockwood, R, Haub, M, Dolezal, B, Almuzaini, K, Schroeder, J. and Zebas, C. (1999). "Muscle Power and Fibre Characteristics Following 8 Weeks of Plyometric Training." Journal of Strength and Conditioning Research **13**(3): 275-279.

Radford, P. (1990). Sprinting. In: Physiology of Sports. T. Reilly, Secher, N., Snell, P. and Williams, C. London, Chapman & Hall.

Ramsay, J., A. Blimkie, C.J.R., Smith, K., Garner, S., MacDougall, J.D., & Sale, D.G. (1990). "Strength training effects in prepubescent boys." Medicine and Science in Sports and Exercise **22**: 605-614.

Rimmer, E. and G. Sleivert (2000). "Effects of a Plyometric Intervention Program on Sprint Performance." Journal of Strength and Conditioning Research **14**(3): 295-301.

Robergs, R. and S. Roberts (2000). Fundamental principles of exercise physiology for fitness, performance and health. Boston, Mcgraw Hill.

Ross, R., Leveritt, M., and Riek, S. (2001). "Neural Influences on Sprint Running - Training Adaptations and Acute Responses." Sports Medicine **31**(6): 409-425.

- Rotstein A., Dotan, R., Bar-Or, O., & Tenenbaum, G. (1986). "Effect of training on anaerobic threshold, maximal aerobic power and anaerobic performance of preadolescent boys." International Journal of Sports Medicine: 281-286.
- Round, J. M., D.A. Jones, J.W. Honour, and A.M. Nevill. (1999). "Hormonal factors in the development of differences in strength between boys and girls during adolescence: a longitudinal study." Annals of Human Biology **26**: 49-62.
- Rowell, L. B. (1986). Human circulation regulation during physical stress. Oxford, Oxford University Press.
- Rowland, T., Varzeas, M. & Walsh, C. (1991). "Aerobic responses to walking training in sedentary adolescents." Journal of Adolescent Health Care **12**: 30-34.
- Rowland, T. W. (1997). "The 'Trigger Hypothesis' for aerobic trainability: a 14-year follow up (editorial)." Pediatric Exercise Science **9**: 1-9.
- Rowland, T. W. and A. Boyajian (1995). "Aerobic response to endurance exercise training in children." Pediatrics **96**: 654-658.
- Sailors, M., & Berg, K. (1987). "Comparison of responses to weight training in pubescent boys and men." Journal of Sports Medicine and Physical Fitness **27**: 30-37.
- Saltin, B. (1969). "Physiological effects of physical conditioning." Medicine and Science in Sports and Exercise **1**(1): 50-56.
- Saraslanidis, P. (2000). "Training for the improvement of maximum speed: flat running or resistance training?" New Studies in Athletics **15**(3-4): 45-51.
- Schmidtbleicher, D. (1985). "Strength training part two: structural analysis of motor strength qualities and its application to training." Science Periodical on Research and Technology in Sport **5**: 1-10.
- Schmidtbleicher, D. (1992). Training for power events. In: Strength and Power in Sport. P. V. Komi. Boston, Blackwell Scientific Publications: 381-395.
- Schmucker, B. and W. Hollman (1974). "The aerobic capacity of trained athletes from 6-7 years of age on." Acta Paediatrica Belgica **28 supplement**: 92-101.
- Schwartz, L., Britten, R.H., and Thompson, L.R. (1928). "Studies in physical development and posture: The effect of exercise on the physical condition and development of adolescent boys." Public Health Bulletin: 179.
- Scoles, G. (1978). "Depth jumping: Does it really work?" Athletic Journal **58**: 74-76.
- Seagrave, L. (1996). "Introduction to sprinting." New Studies in Athletics, Monaco **11**(2-3): 93-113.
- Seagrave, L. (2000). "Neuro-Biomechanics of Maximum Velocity." IAAF Regional Development Centre Bulletin **17**: 21-26.

- Seeman, E., Hopper, J.L., Young, N.R., Formica, C, Goss, P. and Tsalamandris, C. (1996). "Do genetic factors explain association between muscle strength, lean mass and bone density? A twin study." American Journal of Physiology (Endocrinology Metabolism 33), **270**: E320-E327.
- Sermejev, B. (1964). "The influence of specific exercises to flexibility in school-age children." Theorie und Praxis der Korperkultur **5**: 434-436.
- Sharkey, B. J. (1997). Fitness and Health. Champaign, USA, Human Kinetics.
- Sharp, C. (1999). "Some features of the anatomy and exercise physiology of children relating to training." New Studies in Athletics **14**(1): 17-21.
- Shealy, M. J., Callister, R., Dudley, G., & Fleck, S. (1992). "Human torque velocity adaptations to sprint, endurance, or combined modes of training." The American Journal of Sports Medicine **20**(5).
- Singer, R. N. (1970). Motor learning and human performance: An application to physical education skills. London, Macmillan Company.
- Sjodin, B. (1981). The relationship among running economy, aerobic power, muscle power and onset of blood lactate accumulation in young boys (11-15years). Exercise and Sport Biology. P. V. Komi. Champaign, Illinois, Human Kinetics: 57-60.
- Smit, P. J., Daehne, H.O., Von Wyke, G., Steyn, E.S. (1979). Interval training and progressive load principle in novice child swimmers. Swimming II. B. Terauds, Bedingfield & Wengy, Baltimore, University Park Press: 240-249.
- Stewart, K. J., Gutin, B., Fogle, R.K. (1974). The Effects of Physical Training on Cardiovascular Fitness in Children. Annual Convention of the American Association for Health, Physical Education and Recreation, Anaheim, California.
- Stone, M. H., O'Bryant, S., McCoy, L, Coglianesi, R, Lehmkuhl, M and Schilling, B. (2003). "Power and Maximum Strength Relationships During Performance of Dynamic and Static Weighted Jumps." Journal of Strength and Conditioning Research **17**(1): 140-147.
- Stone, M. H., Plisk, S., Stone, M.E., Schilling, B.E., O'Bryant, H.S., and Pierce, K.C. (1998). "Athletic performance development: Volume load - 1 set vs multiple sets, training velocity and training variation." Strength and Conditioning Journal **20**(6): 22-33.
- Suei, K., L. McGillis, R. Calvert, and O. Bar-Or. (1998). "Relationships among muscle endurance, explosiveness and strength in circum-pubertal boys." Paediatric Exercise Science **10**: 48-56.
- Sunberg, S. and R. Elovainio (1982). "Cardiorespiratory function in competitive endurance runners aged 12-16 years compared with ordinary boys." Acta Paediatrica Scandinavia **71**: 987-992.

- Tharp, G. D., Newhouse, R.K., Uffelmann, G., Thorland, W.G., and Johnson, G.O. (1985). "Comparison of sprint and run times with performance on the Wingate Anaerobic Test." Research Quarterly for Exercise and Sport **56**: 73-76.
- Tittel, K. (1992). "Coordination and balance." In: The Olympic book of sports medicine ed. A. Dirix, H.G. Knuttgen, and K. Tittel, Oxford: Blackwell Scientific: 194-211.
- Torim, H. (1988). "The young sprinter." Modern Athlete and Coach **26**(1): 18-21.
- Trudeau, F. and R. Shephard (2005). "Contribution of School Programmes to Physical Activity Levels and Attitudes in Children and Adults." Sports Medicine **35**(2): 89-105.
- Tsolakis, C. K., Vagenas, G.K., & Dessypris, A.G. (2004). "Strength Adaptations and Hormonal Responses to Resistance Training and Detraining in Preadolescent Males." Journal of Strength and Conditioning Research **18**(3): 625-629.
- Tupa, V., Chistyakov, V., Aleshinsky, S., Korneluk, A., Yarmulnik, D., Zhukov, I. and F. Guseinov (1981). "Biomechanics of the take-off in running." Legaya Atletika **9**: 10-11.
- Vaccaro, P. and Clarke, D.H. (1978). "Cardiorespiratory alterations in 9 to 11 year old children following a season of competitive swimming." Medicine and Science in Sports and Exercise **10**: 204-207.
- Van Praagh, E. (2000). "Development of Anaerobic Function During Childhood and Adolescence." Pediatric Exercise Science **12**: 150-173.
- Van Praagh, E., & Franca, N.M. (1998). Measuring maximal short term power during growth. Pediatric Anaerobic Performance. E. V. Praagh. Champaign, Illinois, Human Kinetics: 155-183.
- Verkhoshansky, Y. V. (1996). "Quickness and velocity in sports movements." New Studies in Athletics **11**(2-3): 29-37.
- Verkhoshansky, Y. V. (1996). "Speed training for high level athletes." New Studies in Athletics: 39-49.
- Verkhoshansky, Y. V. (1996). "Principles for a rational organization of the training process aimed at speed development." New Studies in Athletics **11**(2-3): 155-160.
- Vittori, C. (1996). "The European School in sprint training: The experiences in Italy." New Studies in Athletics, Monaco **11**(2-3): 85-92.
- Viviani, F. and G. Casagrande (1990). "Somatotype of Italian male basketball, soccer, and volleyball players." Journal of Sports Science **8**.

Von Döbellen W. and B. O. Erikson (1973). Physical training, growth and maximal oxygen uptake of boys aged 11-13 years. Pediatric Work Physiol: Proc, 4th International Symposium, Israel, Wingate Institute.

Vonstein, W. (1996). "Some reflections on maximum speed sprinting technique." New Studies in Athletics, Monaco **112-3**: 161-165.

Wagner, D. and M. Kocak (1997). "A Multivariate Approach to Assessing Anaerobic Power Following a Plyometric Training Program." Journal of Strength and Conditioning Research **11**(4): 251-255.

Weber, G., Kartodihardjo, W., and Klissouras, V. (1976). "Growth and physical training with reference to heredity." Journal of Applied Physiology **40**(2).

Whitehead, J. (1993). Why children choose to do sport - or stop. In: Coaching children in sport - principles and practice. London, Chapman & Hall.

Wiemann, K. and G. Tidow (1995). "Relative activity of hip and knee extensors in sprinting - implications for training." New Studies in Athletics, Monaco **10**(1): 29-49.

Williams, C. (2007). "Physiological Changes of The Young Athlete and The Effects on Sports Performance." SportEx Medicine. Issue 31, 6-11.

Wilson, G., Newton, R.U., Murphy, A.J., and Humphries, B.J. (1993). "The optimal training load for the development of dynamic athletic performance." Medicine and Science in Sport and Exercise **25**: 1279-1286.

Winckler, G. (1991). "An examination of speed endurance." New Studies in Athletics **6**(1): 27-33.

Yoshida, T., I. Ishiko, and Muraoka, I. (1980). "Effect of endurance training on cardiorespiratory functions of 5 year old children." International Journal of Sports Medicine **1**(2): 91-94.

Young, W. (1993). "Training for Speed/Strength: Heavy vs. Light Loads." National Strength and Conditioning Association Journal **15**(5): 34-42.

Young, W., B. McClean, and J. Ardagna. (1995). "Relationship between strength qualities and sprinting performance." Journal of Sports Medicine and Physical Fitness **35**: 13-19.

Young, W., Benton, D., Duthie, G., and Pryor, J. (2001). "Resistance Training for Short Sprints and Maximum-speed Sprints." Journal of Strength and Conditioning **23**(2): 7-13.

Young, W., James, R., and Montgomery, I. (2002). "Is muscle power related to running speed with changes in direction?" Journal of Sports Medicine and Physical Fitness **42**: 282-228.

Young, W. B., McDowell, M.H., & Scarlett, B.J. (2001). "Specificity of sprint and agility training methods." Journal of Strength and Conditioning Research **15**(3).

Zwiren, L. (1989). "Anaerobic and Aerobic Capacities of Children." Pediatric Exercise Science **1**: 31-44.