Sprint running kinetics and kinematics in youth

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A thesis submitted in fulfillment of the

requirements for the degree of

Doctor of Philosophy

Auckland University of Technology, December 2012

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Michael C. Rumpf ______________________________

Date ______________________________

Co-authored works

Chaper 2-10 of this thesis are comprised of scientific papers that are either published or under review. The percentage contribution of each author is presented below.

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Chapter Eight: Rumpf. M. C., Cronin, J. B., Harrison, C., Ikhwan Nur, M., Sharil, M., Oliver, J. L., Hughes, M. 2012. Asymmetries during running in male youth. *Human Movement Science*.

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Acknowledgements

Firstly, I would like to thank my primary supervisor John Cronin, who has been exceptional in so many different ways. I have learnt so much from our interaction in and outside official meetings - not only with regard to academic problems. Your leadership, guidance and (in general) your attitude towards life cannot be equaled by any other.

Of course, thanks and appreciation needs to go to my secondary supervisors, Jonathan Oliver and Michael Hughes. Your help and guidance has also been greatly appreciated, especially in the last phases of this PhD.

To all my former flat-mates and PhD colleagues Katja, Peni, Elina, Cesar, Travis, Filip, Albert, Kyle and Craig. Thanks for the time, the support and lifestyle we shared the last three years. "We should do it again sometime."

Thanks to all the staff from AUT. Especially to Ruth for never getting tired of answering questions and helping during my time at AUT.

To all subjects and their parents, who volunteered their time and effort. Your hours of sweat and pain on the Woodway were greatly appreciated. In this context, special recognition needs to be given to Rob Taylor from Westlake Boys High School, the Malaysian Crew Ihkwan and Sharil and their staff of the Jungle Gym. Without your help this PhD would have been difficult to complete.

I would also like to acknowledge Auckland University of Technology, ACC and New Zealand Football for providing funding for this PhD.

To my friends from/in Germany. Thanks for traveling the world to celebrate my birthdays. Can't wait to go out with you guys when I am back home again.

Finally to my family and my girlfriend Christine, thanks for all the support and understanding. I can only imagine how hard it was to accept and/or tolerate my work rate and selfishness sometimes. Thanks for taking over other work that needed to be done and supporting me throughout this journey in New Zealand.

Publications arising from this thesis

Published or accepted peer-reviewed articles

Chapters 2-10 have all been submitted to peer-reviewed journals for publication. The details of these publications are as follows:

Rumpf, M. C., Cronin, J. B., Oliver, J. L. and Hughes, M. (2011). Assessing youth sprint ability - methodological issues, reliability and performance data. *Pediatric Exercise Science*, *23*(4): 442-467.

Rumpf, M. C., Cronin, J. B., Pinder, S. D. Oliver, J. L. and Hughes, M. (2012). Effect of different training methods on running sprint times in male youth. *Pediatric Exercise Science*, *24*(2): 170-186.

Peer-reviewed articles currently under review

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Sprint running kinematics and kinetics in pre-peak-height-velocity male children on a non-motorised treadmill: Reliability and normative data. *Sports Biomechanics*.

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. The effect of four different step detection thresholds on the kinematics and kinetics of a 30 metre sprint on a non-motorised treadmill. *Journal of Applied Biomechanics*.

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Kinematic and kinetic variables of maximum running speed in youth across maturation. *Journal of Sport Science*.

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Vertical and leg stiffness and stretch-shortening-cycle change across maturation during maximal sprint running. *Human Movement Science*.

Rumpf. M. C., Cronin, J. B., Harrison, C., Ikhwan Nur, M., Sharil, M., Oliver, J. L., Hughes, M. 2012. Asymmetries during running in male youth. *Physical Therapy in Sports*.

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Acute effects of sled towing on sprint time in male youth of different maturity status. *Pediatric Exercise Science*.

Rumpf. M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. The effect of resisted sprint training on running performance in youth. *Pediatric Exercise Science*.

Conference presentation arising from this thesis

Rumpf, M. C. and Cronin, J. B. Reliability of sprint kinetics & kinematics of youth on a non-motorised treadmill. *Sport Performance Research Institute New Zealand Conference*, Auckland 2010.

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Chapter 1

Preface

Sprint running performance is a fundamental motor task and very important in many sports. Research in adults have shown the importance of kinetic (i.e. horizontal and vertical force) and kinematic (i.e. stride frequency/length, contact time) parameters that comprise sprint running performance (Bosco & Vittori, 1986; Delecluse, Ponnet, & Diels, 1998; Hunter, Marshall, & McNair, 2004; Hunter, Marshall, & McNair, 2005; Kyrolainen, Belli, & Komi, 2001; Luhtanen & Komi, 1978; Mero & Komi, 1986; Mero, Komi, & Gregor, 1992; Nummela, Keranen, & Mikkelsson, 2007; Sinning & Forsyth, 1970; Weyand, Sternlight, Bellizzi, & Wright, 2000) and the differences in these variables between fast and slow athletes (Brughelli, Cronin, & Chaouachi, 2011; Högberg, 1952; Luhtanen & Komi, 1978; Mero & Komi, 1986; Weyand et al., 2000). Due to the importance of speed in many athletic and sporting activities, sprint running performance is considered an important aspect in the long-term athlete development (LTAD) process (Balyi & Way, 2005). However, despite its importance, there is very limited information about sprint running performance development with age (Papaikovou et al., 2009; Philippaerts et al., 2006; Yagüe & De La Fuente, 1998) and similarly a paucity of knowledge (Schepens, Willems, & Cavagna, 1998) regarding underlying mechanisms (i.e. kinetic and kinematics variables).

Generally, sprint running performance development as measured by sprint times over certain distances increased with age (Branta, Haubenstricker, & Seefeldt, 1984; Papaikovou et al., 2009; Philippaerts et al., 2006; Schepens et al., 1998; Yagüe & De La Fuente, 1998) and plateaued after the age of 15 years (Papaikovou et al., 2009; Philippaerts et al., 2006; Yagüe & De La Fuente, 1998) in boys. Schepens et al. (1998) found that the step frequency at maximum velocity remained constant at about 4 Hz independent of age (Schepens et al., 1998). Papaikovou et al. (2009) stated that the development of sprint running performance is linked with factors changing with age such as height or additional development of strength and power (Kaneko, Sasaki, & Fuchimoto, 1987) during childhood. Improvements in strength and power influences sprint running performance through stride length (Ecker, 1996), while improvements in stride frequency are attributed to neuronal factors (Mero, 1998).

The physical development of young athletes is not only influenced by age. Some contend that maturation (Malina, Bouchard, & Bar-Or, 2004) is more important as maturation changes the strength/power ability of youth and therefore sprint running development (Gravina et al., 2008; Mero, 1998). Generally, maturation refers to the timing and tempo of progression towards adulthood (Baxter-Jones, Eisenmann, & Sherar, 2005) and it can be assessed by using x-ray, magnetic resonance imaging (MRI), Tanner staging, anthropometric measures to calculate percent of predicted mature height and peak height velocity (PHV) (Baxter-Jones et al., 2005). Puberty and inherent rise of hormone levels (testosterone and growth hormones) (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around PHV can be seen as an essential part of maturation and seem to markedly influence improvements in strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990) and consequently power output (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero et al., 1990), therefore force production and finally sprint running performance. However, it is unknown how variables associated with sprint running performance change with maturation and therefore it is speculative to conclude how training needs to be conducted to better affect those variables and consequently sprint running performance.

Despite its logical sense, maturation was not seen as a factor influencing so called "windows of trainability", which refers to the best possible timing of application of certain physical training to achieve optimum adaptation (Borms, 1986; Malina, 2008; Viru et al., 1999), for speed/sprint running performance in a popular LTAD model (Balyi, 2005). As it can be observed in figure 1.1, the two suggested windows of trainability for speed/sprint performance are based on chronological age (Balyi & Way, 2005) and occur at the age of 7-9 years (Balyi & Way, 2005; Borms, 1986) and the age of 13-16 years (Balyi & Way, 2005), whilst other references stated 12-16 years (Borms, 1986; Viru et al., 1999).

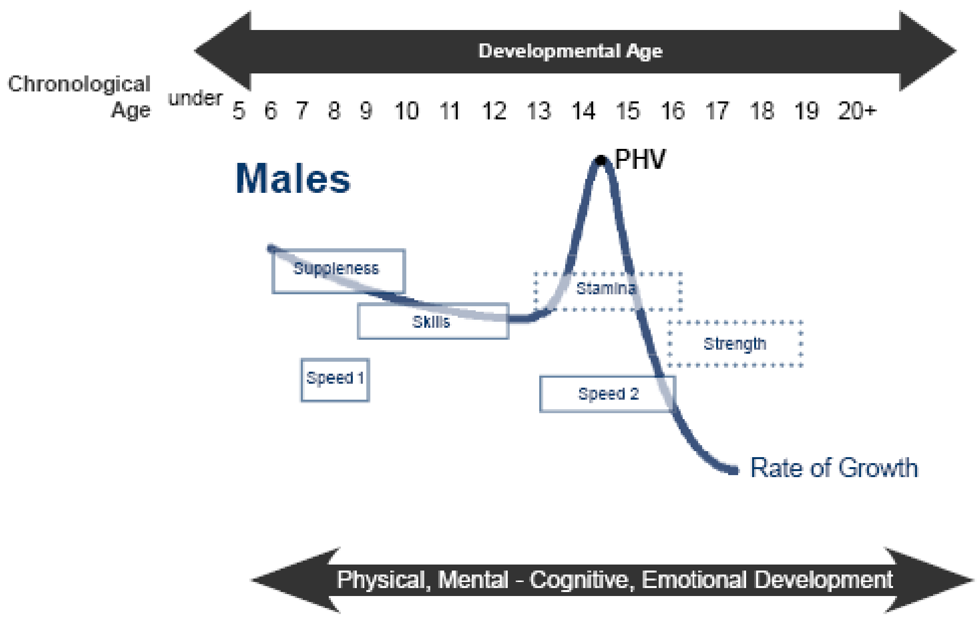

Figure 1.1. Critical periods of trainability of fitness qualities in relation to PHV (Balyi & Way, 2005)

Possible underlying mechanisms for the first period of trainability (speed 1) might be the development of the nervous system (Bengtsson et al., 2005; Gutrecht & Dyck, 1970; Rexed, 1944) and therefore improvements in coordination of arm and leg muscles (Borms, 1986) and subsequent running technique. Improvements during the second window (speed 2 around the age 13-16 years) were attributed to the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier et al., 1969; Kraemer, 1988; Ramos et al., 1998; Round et al.,

1999) and increases in muscle mass, which supports earlier statements. Consequently, additional factors not related to chronological age might be responsible for the development (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004) and trainability of sprint running performance and its determinants. Additionally, other physical qualities thought influential on sprint running performance such as strength (Mero et al., 1990) and consequently power (Armstrong et al., 2001; Armstrong et al., 2000; Forbes et al., 2009; Ioakimidis et al., 2004; Mero et al., 1990) seemed to be affected by maturation and therefore it is highly doubtful if only chronological age is responsible for the second window of trainability for sprint running performance.

Studies that support the theory of windows of trainability are scarce and have resulted in conflicting findings (Philippaerts et al., 2006; Williams, Oliver, & Faulkner, 2011; Yagüe & De La Fuente, 1998) in male youth. While Yagüe and de la Fuente (1998) stated the greatest improvements in a 40 metre dash occurred 16 months prior to and 12 months post-PHV (Yagüe & De La Fuente, 1998), Philippaerts et al. (2006) reported no improvements 18 months prior to PHV and the greatest improvements in sprint performance from 12 to 6 months prior to PHV (Philippaerts et al., 2006) for eight participants. Williams et al. (2011) even supported the concept of optimal trainability based on chronological age, however, also stated that maturity factors such as increased muscle mass and changes in the muscle-tendon architecture were also likely to influence the trainability. Other studies that have investigated training of sprint running performance in male youth (Chelly et al., 2009; Christou et al., 2006; Coutts, Murphy, & Dascombe, 2004; Diallo, Dore, Duche, & van Praagh, 2001; Faigenbaum et al., 2007; Ingle, Sleap, & Tolfrey, 2006; Kotzamanidis, 2003, 2006; Kotzamanidis, Chatzopoulos, Michailidis, Papalakovou, & Patikas, 2005; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010; Meylan & Malatesta, 2009; Thomas, French, & Hayes, 2009; Tsimahidis et al., 2010; Venturelli, Bishop, & Pettene, 2008; Wong, Chamari, & Wisloff, 2010) failed to provide measures of maturation and therefore their contribution to improving understanding with regard to trainability of sprint running performance is limited.

What is obvious is from this brief treatise of the literature is the ambiguity in this field of research. The Balyi Model has achieved global popularity, there is research that suggests maturation will affect the training response, however, there is also research that shows children are trainable outside of the windows identified. More research is needed to establish trainability of children at different stages of maturation and across different training modes.

In conclusion, there are very few studies that have studied the kinematics and kinetics of sprint running performance in youth. To the knowledge of these authors, no studies have comprehensively investigated the influence of maturation on sprint kinematics and kinetics. Furthermore, there is still only limited knowledge about the development and trainability of sprint running performance with regard to maturation in the LTAD process. In particular, there is no information on responsiveness to identical training stimuli in athletes of different maturity status e.g. strength/resistance training methods in pre- vs. post-pubescent athletes. This field of enquiry provides the focus of this thesis.

1.1 Thesis rationale

It would seem that there is some conjecture regarding sprint running performance development and trainability in youth. That is, not only age but more importantly maturation will influence sprint running performance, especially around PHV. If this is the case then the contribution of various mechanical determinants to sprint running performance (e.g. stride length and frequency, horizontal force, vertical stiffness, etc.) needs to be understood with reference to athletes of different maturity status. Furthermore, the effect of different training methods on these variables needs to be understood. No research has undertaken such analysis across different maturity groups. Such analyses will contribute to our understanding of the kinetic and kinematic variables that are important determinants of sprint performance across different maturity stages (pre-, mid- and post-pubescent), which will provide information that guides sprint assessment and programming and therefore long-term athlete development to better effect.

1.2 Originality of the thesis

There are no studies that have evaluated the kinematics and kinetics of sprint running performance in male youth. Furthermore, there is no research that has investigated the reliability of these variables across different maturity status. Also the research specifically investigating and quantifying the effect of specific and non-specific sprint training in youth male is limited. No study has tracked the effect of strength/resisted training on sprint performance in youth male in different maturity status'.

Given the limitations cited in the previous paragraphs the aims of this thesis are to:

Aim 1: Describe the most common tests and associated reliabilities used for assessing sprint running in youth.

Aim 2: Review and quantify all training methods thought to improve sprint running performance in male youth with regard to different maturity status.

Aim 3: Investigate the reliability of kinematic and kinetic variables on a non-motorised treadmill in male youth athletes of pre-pubescent status.

Aim 4: Investigate the kinematic and kinetic determinants of sprint running performance in male youth athletes of different maturity status.

Aim 5: Investigate the effect of strength/resisted training methods on kinematic and kinetic determinants of sprint running performance in male youth of different maturity status.

1.3 Thesis organisation

The overarching focus of the thesis is to improve understanding related to changes in the kinetics and kinematics of sprint running performance in youth and the influence of growth and maturation. Given the scope of such a topic the research focus has been narrowed to address two areas of interest: 1) identification and investigation of kinematic and kinetic variables that are thought to be determinants of sprint running performance; and, 2) their trainability with regard to maturity status. To systematically address the concerns and limitations outlined in the previous sections and address the two areas of interest, the thesis has been constructed as such.

Chapters two and three review the literature with regard to sprint running performance development and chronological age and maturity status of athletes. The methods that have been used to measure sprint running performance are critiqued, data collated and discussed, normative performance data provided and suggestions for future research directions made.

Chapters four to nine consist of cross-sectional experimental studies that: a) determine the reliability of various measures thought to determine sprint running performance of male youth on a non-motorised treadmill (Chapter four); b) determine the reliability of different step detection thresholds of kinetic and kinematic variables on a non-motorised treadmill (Chapter five); c) explore if and to what extent the variables found reliable vary in male youth of different maturity status (Chapters six to eight); and, d) determine if various resisted sprint training (sled towing) loads have a differential effect on subjects of different maturity status (Chapter nine).

Chapter ten investigates the effect of sled towing on the sprint kinetics and kinematics of athletes of different maturity status via a longitudinal study.

Chapter eleven consists of a summary of the main research findings and delimitations of the thesis. Subsequently, recommendations are made for strength and conditioning practitioners with regards to the development and trainability of speed in male youth with regards to chronological and maturity stages. To conclude future research directions are presented.

All chapters are presented in APA format. All have been published or submitted as stand-alone papers to the peer-review journals. Consequently, there is some repetition between the chapters.

An overall reference list from the entire thesis has been collated at the end of the final chapter. The appendices also present relevant peripheral material including informed consent form, ethics approval and subject information sheets.

1.4 Significance of study

The issues relating to training for specific physical qualities are seminal to athlete development and hence central to sport science research. To aid development in this area, research into sprint running performance needs to be systematic and disseminate findings in relation to: 1) validity and reliability of measurement devices and appropriate methods and protocols to test and understand sprint running performance; 2) identification and validation of determinants of sprint running performance across different maturity status; and, 3) development of new or alternative training strategies that may better develop sprint running performance in male youth of different maturity status. The aim of the series of studies presented in this thesis is to contribute to each of these three areas.

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Chapter 2

Assessing youth sprint ability – methodological issues, reliability and performance data

This chapter has been published as referenced below:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2011. Assessing youth sprint ability – methodological issues, reliability and performance data. *Pediatric Exercise Science*, *23*(4):442-467.

2.1 Prelude

Competing in national and international sprinting events require many years of dedication to training. However, despite the need for longitudinal development, most of the scientific knowledge in testing, training and normative data in sprinting is only presented for adults. With more and more young athletes involved in advanced level athletics and long term athlete development programmes, the need for for accurate and reliable tests and performance data in youth is evident. Subsequently, this review will: 1) describe the most common tests used for assessing sprint running in youth; 2) present the associated reliability for the tests; and, 3) present performance data for each assessment where appropriate.

2.2 Introduction

Sprinting is an essential component in many sports. It distinguishes between good and better athletes during team sports performance (Reilly, Williams, Nevill, & Franks, 2000) and can be divided into a number of phases: the start including first step quickness, acceleration, maximum velocity, and deceleration. First step quickness, defined as the first 0-5 metre, is usually included in the acceleration phase, particularly characterised by high propulsion force (Mero, 1988; Sleivert & Taingahue, 2004), and of extreme importance in team sports (Duthie, Pyne, Marsh, & Hooper, 2006; Gregson, Drust, Atkinson, & Salvo, 2010; Keane, Reilly, & Hughes, 1993). The acceleration phase can also be defined as the distance needed to attain maximum velocity. Maximum velocity is the highest speed during the sprint. Deceleration follows the maximum velocity phase and is characterised by a percentage decrease in velocity until the completion of the sprint. Depending on the sport and the type of athlete, the phases of the sprint can have different durations. For example, the acceleration phase of untrained athletes is shorter (Delecluse, 1997) compared to professional sprinters who are able to accelerate until 50-60 metre (Delecluse, 1997; Mero, Komi, & Gregor, 1992).

Testing and monitoring athletes sprinting speed is therefore important and can have different purposes, i.e. comparison between athletes, controlling training efficacy, talent identification, and monitoring long-term-athlete development. However, most of the literature relates to adults, but more and more young athletes are involved in advanced level athletics (Inbar, 1996) and long term athlete/player development programmes, which suggests the needs for accurate and reliable tests and performance data in youth. This review will:1) describe the most common tests used for assessing sprint running in youth; 2) present the associated reliability for the tests; and, 3) present performance data for each assessment where appropriate.

2.3 Methods

2.3.1 Overground running tests

All studies used for the discussion in this section were published in peer reviewed journals or were a part of a book chapter, which included literature citations. Subjects' had to be 5-18 years of age and procedures and measurement equipment had to be detailed. Additional inclusion criteria were the assessment of a single sprint of 40 metre or less in which time was measured with photoelectric cells or a stop-watch. A total of 106 studies were found of which 34 studies were included and 72 excluded in this section. Reasons for exclusion included an insufficient description of the: subject's characteristics; age range; or, assessment procedures i.e. measurement device not given.

As can be observed from table 2.1. and table 2.2. the distances that have been assessed using youth participants ranged from 5 to 40 metre. Two methods were used to quantify the sprinting time of the participants. Timing lights were used in

91% of the studies and 9% used a stopwatch. Twenty-three studies (68%) used the fastest sprint time out of multiple sprints for data analysis, six studies (18%) used the average time of multiple sprints and an additional five studies (15%) did not mention how the sprint time was selected i.e. data analysis.

The total number of subjects from which the performance data was generated was 2864. Of these 2864, 77% were males and the remaining 23% females. Seventy six percent of the studies included used athletic participants, while the remainder were categorised as non-athletic (19%) or the training status was not reported (5%).
In terms of the age of the participants, the age range was 8 to 18 yrs with the mean age of 13.95 years for the male sample and a mean age of 13.7 for the females. Only two studies described the maturation of the participants (Christou et al., 2006; Kruger & Pienaar, 2009a) and two studies reported sprinting time in relation to the subjects' peak height velocity (Philippaerts et al., 2006; Yagüe & De La Fuente, 1998).

Table 2.1. Cross-sectional studies that assessed overground sprinting performance of boys

Author	Subject Characteristics Number and gender Training status Age/maturation	Procedures Equipment Surface	Dependent Variables	Times
Babel et al. (2005)	17♂	30 m on a synthetic track using photo-electric cells with a start 1 m behind the first light	30 m time (s)	
	Non-athletic boys TS 1			5.59
	8 Caucasian group 11.2 y, 1.41 m			5.51
	9 Afro-Caribbean group 11.7 y, 1.47 m			
Berg et al. (1986)	14♂, 11.8 y, 1.54 m, 42.2 kg	Average over 2 sprints on a grass athletic field, measured with a hand-held stop watch	30 m time (s)	5.68
Buttifant et al. (1999)	21♂ junior national and state representative football players, 16.1 y, 1.75 m, 69.2 kg	2 x 20 m sprints on a grass surface, measured with timing gates	20 m time (s)	3.01
Christou et al. (2006)	26♂ 4.3 y of soccer experience	The fastest out of two 30 m sprints using electronic photo cells placed 50 cm above ground for the first gate and on the height of the subjects head for the following two gates. Subjects had to start sprinting 30 cm behind a line.		
	Experimental 1: 9♂, 13.8 y, 1.62-1.65 m, 52-57.5 kg, TS 4.0-4.3		Experimental 1 10 m (s) 30 m time (s)	Pretraining, 8 weeks, 10 weeks 2.16, 2.18, 2.09 5.07, 5.16, 4.94
	Experimental 2: 9♂, 13.3 y, 1.63-1.65 m, 54.1-55.3 kg, TS 3.9-4.2		Experimental 2 10 m (s) 30 m time (s)	 2.0, 2.04, 1.98 4.85, 4.88, 4.85
	Control: 8♂, 13.3 y, 1.63-1.66 m, 57.4-55.8 kg, 3.8-4.2 TS		Control 10 m (s) 30 m time (s)	 2.18, 2.20, 2.11 5.20, 5.26, 5.22
Colella et al. (2009)	105♂ 8-10 y, 9.2 y, maturation measured but no data given	Best of two 10 and 20 m sprints from a standing start measured with a handheld stopwatch	10, 20 m time (s)	
	Overweight♂ 17♂, 8.4 y, 1.33 m, 42.46 kg 17♂, 9.5 y, 1.40 m, 45.96 kg		Overweight♂ 8.4 y 9.5 y	 2.61, 4.95 2.47, 4.56

	18♂, 10.3 y, 1.45 m, 51.66		10.3 y	2.31, 4.22
	Not overweight♂		Not overweight♂	
	18♂, 8.4 y, 1.29 m, 27.03 kg		8.4 y	2.45, 4.45
	17♂, 9.5 y, 1.31 m, 28.13 kg		9.5 y	2.31, 4.29
	17♂, 10.3 y, 1.41 m, 35.52 kg		10.3 y	2.15, 3.92
Dourado et al. (2007)	100♂U14 soccer players , 1.57 m, 46.12, kg	40 m sprints using electronic timing system	10, 40 m time (s)	1.78, 6.21
	87♂U16 soccer players, 1.71 m, 61.08 kg			1.83, 5.65
	169♂U18 soccer players, 1.74 m, 65.29 kg			1.79, 5.50
Gabbett (2002)	88♂ rugby players	Fastest out of two 40 m sprints using electronic gates		
	Different amount of playing experience			
			10, 20, 40 m time (s)	
	Forwards:		Forward:	
	13♂, 12.5 y, 57 kg		12.5 y	2.6, 4.24, 7.50
	7♂, 13.5 y, 67.7 kg		13.5 y	2.44, 3.99, 7.00
	11♂, 14.5 y, 76.5 kg		14.5 y	2.25, 3.72, 6.58
	12♂, 15.4 y, 75.5 kg		15.4 y	2.22, 3.61, 6.17
	Backs:		Backs:	
	14♂, 12.3 y, 44.8 kg		12.3 y	2.46, 4.04. 7.11
	10♂, 13.7 y, 52.1 kg		13.7 y	2.24, 3.7, 6.47
	12♂, 14.6 y, 62.1 kg		14.6 y	2.21, 3.62, 6.26
	9♂, 15.6 y, 64.8 kg		15.6 y	2.17, 3.55, 6.00
Gissis et al. (2006)	48♂ football players	10 m sprint using a dual laser beam in connection with a digital chronometer. Best out of three trials from a standing position was used for further data analysis	10 m time (s)	
	18♂ Elite, 16.3 y, 1.69 m, 68.17 kg		Elite	1.95
	18♂ Subelite, 16.4 y, 1.69 m, 67.74 kg		Sub-elite	2.14
	18♂ Recreational, 16.2 y, 1.69 m, 69.87 kg		Recreational	2.21
Hoare (2000)	125♂ Participants of Australian U16 basketball championships	Fastest of all split time in three 20 m sprints on a dry grass surface using electronic timing gates, starting with the front foot on the start line		
	125♂, 15.4 y		5, 10, 20 time (s)	
	28♂, 1.78 m, 68.1 kg			1.08, 1.83, 3.12
	25♂, 1.81 m, 71.3 kg			1.10, 1.84, 3.15
	31♂, 1.86 m, 76.4 kg			1.13, 1.89, 3.21
	25♂, 1.91 m, 83.8 kg			1.12, 1.88, 3.24
	16♂, 1.95 m, 84.5 kg			1.10, 1.87, 3.21

Hoshikawa et al. (2007)	24 ♂ academy youth football players, 17.0 y, 1.72 m, 63.7 kg	20 m sprint on a grass field measured by photocells	5 m time (s) 10 m time (s) 15 m time (s) 20 m time (s)	1.02 1.78 2.45 3.08
Kilding et al. (2008)	24♂ football players 10.4 y, 4.1 years of playing experience	Average of three times 20 m sprints using dual electronic timing gates, 0.75 m above ground level, 0.5 m behind the starting line	20 m time (s)	Pre-, Posttest, Average
	12♂Experimental 1.32 m, 34.3 kg		Experimental	3.60, 3.52, 3.56
	12♂Control 1.37 m, 36 kg		Control	3.74, 3.81, 3.78
Kollath et al. (2006)	131♂ football players	Best out of three 20 m sprints on an artificial turf, from a standing split start position measured by timing gates	10, 20 m time (s)	
	11♂, 8.3 y, 1.38 m, 32 kg 9♂, 10.1 y, 1.45 m, 35 kg 10♂, 11.0 y, 1.50 m, 40 kg 16♂, 11.8 y, 1.50 m, 39 kg 13♂, 12.8 y, 1.59 m, 46 kg 17♂, 13.6 y, 1.64 m, 52 kg 13♂, 14.8 y, 1.74 m, 62 kg 12♂, 15.6 y, 1.69 m, 57 kg 17♂, 16.7 y, 1.77 m, 71 kg		8.3 y 10.1 y 11.0 y 11.8 y 12.8 y 13.6 y 14.8 y 15.6 y 16.7 y	2.13, 3.85 2.14, 3.76 2.04, 3.64 2.08, 3.60 2.07, 3.62 1.97, 3.47 1.79, 3.17 1.77, 3.10 1.70, 2.98
Kotzamanidis (2003)	30♂, non-athletic	Best out of two 30 m indoor sprints measured with an electronic chronometer connected to opto-reflective switches	Time (s)	Pre-, Posttest, Average
	Experimental group: 15♂, 11.1, 1.57 m, 49.6 kg		0-10 m 0-20 m 0-30 m	2.19, 2.14, 2.17 3.82, 3.68, 3.75 5.45, 5.27, 5.36
	Control group: 15♂, 10.9, 1.54 m, 48.7 kg		0-10 m 0-20 m 0-30 m	2.29, 2.30, 2.30 4.04, 4.07, 4.06 5.74, 5.77, 5.76
Kotzamanidis (2005)	35♂ Physical educational student	Fastest of two 30 m sprints using photocells placed at shoulder height. Start from the standing position	30 m time (s)	Pre-, Posttest, Average
	Combined resistance and speed training (CRST) 12♂, 17 y, 1.78 m, 73.5 kg		CRST	4.34, 4.19, 4.27

	Resistance training only (RTO) 11♂, 17.1 y, 1.75 m, 72.5 kg		RTO	4.33, 4.31, 4.32
	Control (CO) 12♂, 17.8 y, 1.76 m, 75 kg		CO	4.50, 4.48, 4.49
Kotzamanidis (2006)	30♂ Healthy non-athletic boys 10-11, 1.54-1.56 m, 48.7-49.6 kg, TS 1	Fastest of two 30 m sprints on an indoor sport hall, using electronic chronometer connected to 4 pairs of opto-reflective switches		
	Experimental group 15♂, 11.1 y, 1.57 m, 49.6 kg, TS 1		Experimental group 0-10 time (s) 10-20 time (s) 20-30 time (s) 0-30 m time (s)	Pre-, Posttest, Average 2.24, 2.19, 2.22 1.71, 1.65, 1.68 1.61, 1.56, 1.59 5.55, 5.41, 5.48
	Control group 15♂, 10.9 y, 1.54 m, 48.7 kg, TS 1		Control group 0-10 time (s) 10-20 time (s) 20-30 time (s) 0-30 m time (s)	Pre-, Posttest, Average 2.29, 2.30, 2.30 1.75, 1.78, 1.77 1.70, 1.74, 1.72 5.74, 5.77, 5.76
Kruger and Pienaar (2009a)	39♂ talented children 12.1 y, 1.41 m, 34.3 kg, Diverse TS	Fastest of two 100 m sprints using electronic timing lights	0-5 time (s)	1.8
Kruger and Pienaar (2009b)	62♂ school children	Fastest of two 100 m sprints using electronic timing lights.		
	Experimental group 16♂, 10.92 y		Experimental group 0-40 m time (s)	Pre-, Posttest, Average 7.41, 7.3, 7.36
	Control group 16♂, 12.38 y		Control group 0-40 m time (s)	Pre-, Posttest, Average 7.44, 7.6, 7.52
Le Gall (2002)	328♂ football players 11-18	Fastest of two 40 m sprints using photoelectric cells	10, 10-20, 20-30, 30-40, 40 time (s)	
	10♂, 11-11 ½ y, 39.8 kg 10♂, 12 y, 41.2 kg 22♂, 12 ½ y, 42.5 kg 35♂, 13 y, 45.6 kg 31♂, 13 ½ y, 49.9 kg 57♂, 14 y, 56.6 kg 36♂, 14 ½ y, 58.2 kg 15♂, 15 y, 59.7 kg		11-11 ½ y 12 y 12 ½ y 13 y 13 ½ y 14 y 14 ½ y 15 y	2.01, 1.43, 1.38, 1.37, 6.19 2.01, 1.40, 1.34, 1.33, 6.08 2.00, 1.40, 1.33, 1.32, 6.05 1.99, 1.39, 1.32, 1.31, 6.01 1.96, 1.37, 1.30, 1.29, 5.92 1.94, 1.34, 1.26, 1.25, 5.79 1.91, 1.31, 1.24, 1.24, 5.70 1.91, 1.30, 1.24, 1.23, 5.68

	27♂, 15 ½ y, 62.6 kg		15 ½ y	1.90, 1.31, 1.23, 1.21, 5.65
	21♂, 16 y, 64.7 kg		16 y	1.87, 1.28, 1.20, 1.17, 5.52
	44♂, 17 y, 66.3 kg		17 y	1.85, 1.27, 1.19, 1.17, 5.48
	20♂, 18 y, 68.1 kg		18 y	1.85, 1.27, 1.19, 1.17, 5.48
Lidor et al. (2005)	279♂, national trials in handball	Best of two 20 sprints from a stationary start with the front foot behind the starting line. Time was measured using a handheld stopwatch	20 m time (s)	
	U12♂			
	29		Selected	3.66
	118		Non-selected	3.81
	U13♂			
	24		Selected	3.55
	109		Non-selected	3.67
	U14♂			
	18		Selected	3.44
	42		Non-selected	3.54
Luhtanen et al. (2002)	106 football players from six First Division clubs	30 m sprint measured with photocells	30 m time (s)	
	17♂, 18 y		18 y	4.26
	21♂, 16 y		16 y	4.41
Maio Alves et al. (2010)	23♂ football players	Best of two 5 metre sprint measured with photoelectric cells	5 m time (s)	Pre-, Posttest, Average
	17.4 y, 1.75, 70.3 kg		Experimental 1	1.09, 0.99, 1.04
			Experimental 2	1.13, 1.06, 1.10
			Control	1.13, 1.11, 1.12
McMillan et al. (2005)	11♂ football players, 16.9 y, 1.77 m, 70.6 kg	Average of three 30 m sprint runs, starting behind the first gate, on an indoor track, using photocells	10 m time (s)	Pre-, Posttest, Average 1.96, 1.96, 1.96
Meyer et al. (2005)	103♂State selection football players	Mean time of the best four out of five 30 m indoor sprints, starting 1 m behind the first timing gate	5, 10 m time (s)	
	30♂U14, 1.64 m, 53 kg			1.04, 1.82
	29♂U15, 1.71 m, 61 kg			1.00, 1.75
	22♂U16, 1.75 m, 67 kg			1.01, 1.75
	12♂U17, 1.77 m, 69 kg			0.99, 1.71
	10♂U18, 1.77 m, 72 kg			0.99, 1.70

Meylan and Malatesta (2009)	25♂ football players 14♂U13, 1.60 m, 49.0 kg 11♂U13, 1.64 m, 47.9 kg	Better of two 10 metre sprints measured by infrared photoelectric cells, starting 0.3 m behind the first gate	10 m time (s)	Pre-, Posttest, Average 1.96, 1.92, 1.94 2.06, 2.01, 2.04
Reilly et al. (2000)	*31*♂, 16.4 years 16♂ elite, 1.71 m, 63.1, kg 15♂ sub-elite, 1.75 m, 66.4 kg	Average of three 30 m sprints measured by electronic timing gates	5, 30 m time (s)	 1.04, 4.31 1.07, 4.46
Tumilty (2000)	21♂ U17 national australian football players	Three 20 m sprints using dual beam timing gates, starting with the front foot on the starting line at the first gate. Best split times from all runs	5 m time (s) 10 m time (s) 20 m time (s)	1.11 1.85 3.12
Venturelli et al. (2008)	16♂ members of a football team involved in the national championship 11y, 1.50m, 40.5 kg, TS 1	Best out of three 20 m sprints on a grass turf using photoelectric cells	20 m time (s)	Pre-, Posttest, Average
	7♂, Sprint training group (STG)		STG	3.75, 3.66, 3.71
	9♂, Coordination training group (CTG)		CTG	3.64, 3.56, 3.60
Wong et al. (2009)	70♂ U14 regional representative football players 10 GK, 13.4 y, 1.69 m, 54.6 kg 20 DF, 13.3 y, 1.67 m, 56.2 kg, 25 MF, 13.4 y, 1.65 m, 52.2 kg 15 FW, 13.0 y, 1.56 m, 43.9 kg	Fastest out of three 30 m spritns using photoelectric cells, with split times every 10 m and the front foot was placed right behind the starting line	10, 30 m time (s) 10 GK 20 DF 25 MF 15 FW	 2.06, 4.92 2.09, 4.81 2.05, 4.82 2.07, 4.96
Wong et al. (2010)	62♂, U14 regional representative football players Experimental 28♂, 13.5 y, , 1.67 m, 52.0 kg	30 m sprint from a stationary start with the front foot right behind the starting line, measured with infrared photoelectric cell. Best out of three trials was used for analysis	10, 30 m time (s) 10 m time (s) 30 m time (s)	Pre-, Posttest, Average 2.05, 1.95, 2.00 4.85, 4.74, 4.80
	Control 23♂, 13.2 y, 1.64 m, 52.5 kg		10 m time (s) 30 m time (s)	2.07, 2.04, 2.06 4.95, 5.00, 4.98

Key: ♂ = Male, PHV = Peak Height Velocity; TS = Tanner Stage

Table 2.2. Cross-sectional studies that assessed overground sprinting performance of girls

Author (Ref)	Subject Characteristics Number and gender Training status Age/maturation	Procedures Equipment Surface	Dependent Variables	Times
Colella et al. (2009)	88♀ 8-10 y, 9.2 y, maturation measured but no data given	Best of two 10 and 20 m sprints from a standing start measured with a handheld stopwatch	10, 20 m time (s)	
	Overweight♂		Overweight♀	
	17♂, 8.3 y, 1.32 m, 40.35 kg		8.3 y	2.71, 5.11
	18♂, 9.5 y, 1.38 m, 44.09 kg		9.5 y	2.58, 4.78
	18♂, 10.2 y, 1.43 m, 50.49 kg		10.2 y	2.50, 4.63
	Not Overweight♀		Not Overweight♀	
	18♀, 8.3 y, 1.28 m, 27.27 kg		8.3 y	2.64, 4.87
	17♀, 9.5 y, 1.32 m, 28.21 kg		9.5 y	2.5, 4.72
	17♀, 10.2 y, 1.40 m, 34.47 kg		10.2 y	2.41, 4.57
Ellis et al. (2000)	17♀ U18 state level female netball players	Three 20 m sprints using dual beam timing gates, starting with the front foot on the starting line at the first gate. Best split times from all runs	5 m time (s) 10 m time (s) 20 m time (s)	1.19 2.01 3.47
Ellis et al. (2000)	76♀ U17 female netball players	Three 20 m sprint overground, using double beam timing gates, starting with the front foot on the starting line at the first gate. Best split times from all runs	5 m time (s) 10 m time (s) 20 m time (s)	1.23 2.05 3.49
Ellis et al. (2000)	11♀ U17 state level female netball players	Three 20 m sprints, using dual beam timing gates, starting with the front foot on the starting line at the first gate. Best split times from all runs	5 m time (s) 10 m time (s) 20 m time (s)	1.18 2.09 3.41
Fedotova (2001)	141♀ Well-trained young female field hockey players	30 m sprint on a track using stop-watch	30 m time (s)	
	16♀, 10 y, 1.39 m, 33.57 kg		10 y	5.83
	15♀, 11y, 1.43 m, 35.34 kg		11 y	5.62
	20♀, 12y, 1.50 m, 39.07 kg		12 y	5.42
	14♀, 13y, 1.57 m, 43.31 kg		13 y	5.30
	20♀, 14y, 1.60 m, 49.84 kg		14 y	5.23
	15♀, 15y, 1.63 m, 53.99 kg		15 y	5.11
	15♀, 16y, 1.64 m, 57.98 kg		16 y	4.95
	14♀, 17y, 1.65 m, 59.95 kg		17 y	4.87
	12♀, 18y, 1.66 m, 60.59 kg		18 y	4.79
Hoare (2000)	123♀ Participants of Australian U16 basketball	Fastest of all split time in three 20 m sprints on a dry grass surface using electronic timing gates, starting with the front foot on the		

	championships	start line		
			5, 10, 20 time (s)	
	130♀, 15.2 y		♀PG	1.18, 1.98, 3.40
	32♀PG, 1.66 m, 57.8 kg		♀OG	1.19, 2.01, 3.46
	30♀OG, 1.69 m, 61.6 kg		♀SF	1.28, 2.08, 3.56
	17♀SF, 1.73 m, 64.1 kg		♀PF	1.25, 2.07, 3.53
	25♀PF, 1.77 m, 69.4 kg		♀C	1.19, 2.03, 2.53
	19♀C, 1.81 m, 70.5 kg			
Hoare and Warr (2000)	17♀ selected football players 15.4 y, 1.64 m, 55.3 kg	Fastest of all split times in three 20 m sprints using electronic timing gates, starting with the front foot up on the start line, measured on grass surface	5 m time (s) 10 m time (s) 20 m time (s)	1.18 2.01 3.47
Lidor et al. (2005)	126♀, national trials in handball	Best of two 20 sprints from a stationary start with the front foot behind the starting line. Time was measured using a handheld stopwatch	20 m time (s)	
	U12♀			
	20		Selected	3.98
	54		Non-selected	3.90
	U13♀			
	20		Selected	3.83
	51		Non-selected	3.94
Luhtanen et al. (2002)	35♀ football players from six First Division clubs	30 m sprint measured with photocells	30 m time (s)	
	17♀, 18 y		18 y	4.90
	18♀, 16 y		16 y	4.92

Key: ♀ = Female, PHV = Peak Height Velocity; TS = Tanner Stage

2.3.1.1 Methodological issues

As can be observed from table 2.1. and table 2.2., several methodological issues make comparison of the data difficult. Time measurement devices were single or double beam timing gates and stop-watches. The greatest measurement error was associated with the use of stopwatches and the least with dual beam infra red timing light technology. Different starting stances (standing start, split start, three point start, track and field start), starting distance behind the start line (30 cm – 20 metre) and different running surfaces will influence the sprint time. Several studies also did not mention which data (fastest vs. average trial) were used for data analysis.

2.3.1.2 Reliability of overground sprint running assessments

A total of seven studies reported the reliability of overground sprinting in youth population (Christou et al., 2006; Drinkwater, Hopkins, McKenna, Hunt, & Pyne, 2007; Gabbett, 2002; Kotzamanidis, 2003, 2006; Kotzamanidis, Chatzopoulos, Michailidis, Papalakovou, & Patikas, 2005; Kruger & Pienaar, 2009b). Intra- and inter-day CVs of sprint time for sprinting distances of 10, 20, 30 and 40 metres ranged from 0.83% - 2.07% (Christou et al., 2006; Gabbett, 2002). Intra- and inter-day ICCs ranged from 0.88 and 0.98 for 10 – 40 metres (Christou et al., 2006; Gabbett, 2002; Kotzamanidis, 2006) and Pearson correlation coefficients ranged from 0.90 – 0.97 (Kotzamanidis, 2003, 2006; Kotzamanidis et al., 2005; Kruger & Pienaar, 2009b).

2.3.2 Torque treadmill

In addition to overground sprinting, a torque treadmill was also used to assess sprint kinetics and kinematics (Chelly & Denis, 2001; Falk et al., 1996). A motor built into the treadmill equalises the friction caused by the subjects' weight, while a harness connected to a strain gauge measure the subjects' horizontal force, with a goniometer recording the angle at which horizontal force was created. Horizontal displacement of the belt was measured by a sensor system attached to the rear rolling drum (Jaskólski, Veenstra, Goossens, Jaskólska, & Skinner, 1996).

2.3.2.1 Methodological issues

Generally, studies which examined single running sprints with a duration over 10 seconds were excluded. The highest speed and power during sprinting on a torque treadmill was achieved within the first 10 seconds. Longer test durations will affect mean power output, trigger different energy systems and test other running qualities/abilities of the participants. Peak power is a measurement of the highest power achieved in a defined period of time and is usually the averaged peak power of the number of foot strikes in that time period. Methodological issues also arise when a rolling or a standing start is used for data collection. Furthermore, the elasticity of the tether will affect horizontal force output.

2.3.2.2 Reliability of torque treadmill sprint running assessments

One study investigated the reliability of peak and mean power of paediatric population performing a 30-second sprint on a torque treadmill (Falk et al., 1996). Inter-day ICC values were 0.80 and 0.81 for peak and mean power respectively.

2.3.3 Non-motorised treadmill

A non-motorised treadmill has been used to measure sprint kinetics and kinematics in youth (Bloxham, Welsman, & Armstrong, 2005; Oliver, Armstrong, & Williams, 2009; Oliver, Williams, & Armstrong, 2006; Oliver, Armstrong, Williams, 2007; Ratel, Williams, Oliver, & Armstrong, 2004; Ratel, Williams, Oliver, & Armstrong, 2006; Sutton, Childs, Bar-Or, & Armstrong, 2000; van Praagh, Fargeas, Léger, Fellmann, & Coudert, 1993; Yanagiya, Kanehisa, Kouzaki, Kawakami, & Fukunaga, 2003). A horizontal load cell attached with a harness to the runner measures the horizontal force. Typically, four individual load cells mounted under the running surface measures the vertical force whilst running. The running speed can be monitored by optical speed photomicrosensors.

2.3.3.1 Methodological issues

Considerations about peak and mean power are similar to the torque treadmill. The initial resistance of the treadmill belt is another issue that needs to be considered. Studies did not report the initial resistance of the non-motorised treadmill belt, which affects inertia and subsequent sprint kinematics kinetics. In relation to the treadmill resistance, it can be expected that the weight/strength of the participant would influence the participant's ability to overcome the initial resistance of the treadmill and thus lighter/weaker participants at a greater disadvantage.

2.3.3.2 Reliability of non-motorised treadmill sprint running assessments

The reliability of mean and peak velocity, and mean and peak power output have been investigated on a non-motorised treadmill (Oliver et al., 2006). Inter-day reliability values for those variables were within 2.88 and 8.32%. Sutton et al. (2000) presented absolute values for mean (15.3 Watts) and peak (26.6 Watts) power as a coefficient of repeatability. A summary of all reliability values of sprint running assessments can be observed in table 2.3.**Table 2.3**

Table 2.3. Absolute and relative reliability of sprint assessments

		Absolute		Relative	
		CV	Pearson Correlations	ICC	
Assessment	**Author**	Value (Variable)	Value (Variable)	Value (Variable)	**Miscellaneous**
Overground	Christou et al. (2006)	1.46% (10m) 0.83% (30m)		0.96 (10m) 0.98 (30m)	Intra-day reliability
Overground	Drinkwater et al. (2007)	1.30% (20m)			Inter-day reliability
Overground	Gabbett (2002)	2.07% (10m) 1.52% (20m) 1.25% (40m)		0.88 (10m) 0.89 (20m) 0.92 (40m)	Inter-day reliability
Overground	Kotzamanidis (2003)		0.90 (10m) 0.91 (20m) 0.93 (30m)		Not stated
Overground	Kotzamanidis (2005)		0.97 (30m)		Intra-day reliability
Overground	Kotzamanidis (2006)		0.90 – 0.96 (diverse)		Inter-day reliability
Overground	Kruger and Pienaar (2009)		0.95 (100m)		Intra-day reliability
Torque treadmill	Falk et al. (1996)			0.80 (PP) 0.81 (MP)	Inter-day reliability
Non-motorised treadmill	Oliver et al. (2006)	2.88% (PV) 2.59% (MV) 8.32% (PP) 5.41% (MP)			Inter-day reliability
Non-motorised treadmill	Sutton et al. (2000)		Coefficient of repeatability: 26.6 W (PP) 15.3 W (MP)		Intra-day reliability

Key. CV = Coefficient of Variation, ICC = Intraclass Correlation Coefficient, PV = Peak Velocity, MV = Mean Velocity, PP = Peak Power, MP = Mean Power

2.4 Results

2.4.1 Performance data of overground sprinting

Specific performance data for different populations, distances, gender and assessement methodologies can be observed in table 2.1 and table 2.2. Figure 2.1 and figure 2.2 summarise this data so as to provide insight into the trends regarding sprint performance over time (chronological age). The reader needs to be cognisant of the limitations cited previously when viewing this data. Average sprint times for male subjects (n = 2864) over 5, 10, 20, 30, and 40 metre calculated from all subjects and age groups, are shown in figure 2.1. Average sprint time for boys decreased markedly with age over all distances until approximately the age of 15 years, after which the rate in decrease of sprint times lessened (i.e. 16-18 years).

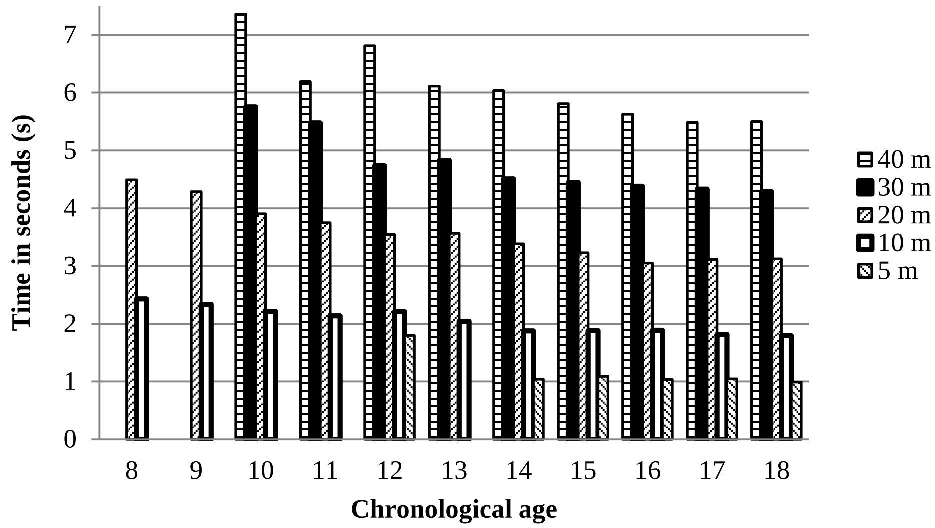

Figure 2.1. Sprint times over 5-40 metre distances for males 8 to 18 years of age

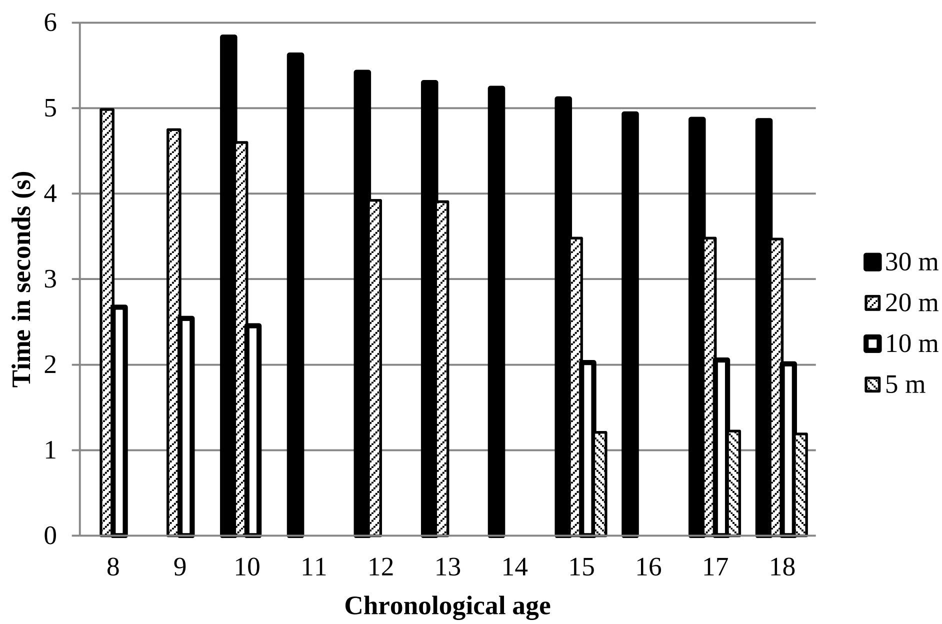

Figure 2.2. Sprint times over 5-40 metre distances for females 8 to 18 years of age

Average sprint times for female subjects (n = 670) over 5, 10, 20, 30, and 40 metre, calculated from all subjects and age groups, are shown in figure 2.2. It seems that when females are compared to males at the same chronological age, the male times were less over all distances. Average sprint time for girls decreased markedly with age over all distances until approximately the age of 16 years, after which the rate in decrease of sprint times lessened (i.e. 17-18 years).

2.4.2 Performance data of torque treadmill

Only one study measured single sprint performance with a duration of less than 10 seconds using this technology (Chelly & Denis, 2001). Maximum velocity, mean power, mean power per kg body weight of 11 male handball players (< 18 years old) during an eight second sprint on a torque treadmill were measured (see table 2.4). However, a measurement of participant's maturation was not included. There is a need for further research in this area.

Table 2.4. Cross-sectional studies that assessed sprinting performance using a torque treadmill

Author (Date)	**Subject Characteristics** Number and gender Training status Age/maturation	**Procedures** Equipment	**Dependent** Variables	**Results**
Chelly and Denis (2011)	11♂, 16 y, 1.79 m, 68 kg	8 s sprint on a torque treadmill	Vmax (m/s) MP (W) MP per kg (W/kg)	6.1 654 9.8

Key. PHV = Peak Height Velocity; Vmax (m/s) = Maximum running speed, PV = Peak Velocity, PP = Peak Power, MP = Mean Power

2.4.3 Performance data of non-motorised treadmill

No study investigated single sprint performance with a duration of below 10 seconds using youth participants which also included measurement of maturation. There is a need for further research in this area.

2.5 Discussion and conclusions

Measuring sprint performance of youth can have various purposes and use different technologies and protocols. Running over-ground is still the easiest, most popular and accurate measurement of youth's sprint ability. However, the variables of interest are typically sprint times between timing lights from which average velocities can be calculated. Whilst valuable in terms of monitoring sprint performance, this information is extremely limited in terms of understanding the mechanical determinants of sprint performance. In this regard, a torque or a non-motorised treadmill can provide mechanistic information on sprint kinematics and kinetics in youth. However, there are a limited number of studies that have used this type of technology in youth and the reliability of many of the variables that can be quantified from these treadmills for the most part have not been established. In addition, the utilisation of this type of technology can be used to perform cross-sectional and longitudinal studies across age and maturity groups, which could give insight into those variables that guide programming to better effect and possibly identify windows of trainability.

Chapter 3

Effect of different training methods on running sprint times in male youth

This chapter has been published as referenced below:

Rumpf. M. C., Cronin, J. B., Pinder, S. D., Oliver, J. L., Hughes, M. 2012. Effect of different training methods on running sprint times in male youth. *Pediatric Exercise Science*, *24*(2):170-186.

3.1 Prelude

Besides reliable protocols in testing and normative data for sprinting in youth, appropriate training is crucial in the long term athlete development process. The long term athlete development process is defined into specific stages in which the training is thought to match the physical development of the individual athlete. More precisely, sprint development is thought to be influenced by age. However, two distinct time periods in the athletes' development have been identified in which training is thought to be most effective. The two so called "critical periods of trainability" or "periods of accelerated adaption to training" are thought to appear between the age of 7-9 and 13-16 in males. With regards to the physical development of male individuals, it seems that especially the second period is influenced by puberty and therefore biological maturation. Consequently, changes in hormone volume and the ability to utilise strength training in the development of sprinting will influence the training. However, whether this or any other training is more efficient in specific developmental stages is currently unknown. Therefore, the purpose of this review is to quantify the effects of different training methods on sprint times in male youth.

3.2 Introduction

Sprint running is an essential component to many sporting performances. Given this importance, the development of sprint ability is thought critical in athlete development. While Katch (1983) claimed no possible training-induced changes in muscular and cardiovascular function after training in pre-pubertals, more recent literature stated so-called critical periods for training from age 5-9 (Branta, Haubenstricker, & Seefeldt, 1984) and 12-15 (Borms, 1986) for speed training. These periods have been termed "windows of accelerated adaptation to training" or "windows of trainability" (Balyi & Way, 2005). Even though the central nervous system undergoes rapid changes in terms of myelination in the first 2-5 years of life (Gutrecht & Dyck, 1970; Lowrey, 1973; Valladian & Porter, 1977; Webster & Favilla, 1984), it is thought this process is not complete until sexual maturation (Jacobson, 1963; Wilmore & Costill, 1994) or even adulthood (Benes, Turtle, Khan, & Farol, 1994; Friede, Brzoska, & Hartmann, 1985). Given this information, training to promote neural adaptation during this stage of maturation may be beneficial.

Hence, appropriate training that is supposed to stimulate intermuscular coordination and/or fast movements (e.g. stride frequency) would seem appropriate before complete myelination of the nervous system (Bengtsson et al., 2005; Mero, 1998). Van Praagh (van Praagh, 1998) suggested training methods that target the neural/neuromuscular system of the athletes to improve coordination, movement efficacy, speed of movement or stride frequency should be used to optimise effectiveness of training during this period (5-9 years of age).

The second phase of “accelerated adaptation to training” has been suggested to appear at the age of 12-15 (Borms, 1986; Viru et al., 1999), which is approximately around the onset of peak height velocity (PHV) and the onset of puberty in boys. Improvements in strength and consequently in power output are primarily attributed to the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around PHV. Sprint training that focuses on the muscular system to improve strength, therefore power output and consequently sprint running speed, might be more appropriate at age 12-17 for male youth, due to the reason that strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990), power measured in a Wingate test (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000), jump (Mero et al., 1990), leg flexion/extension test (Forbes et al., 2009;

Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004), and speed was affected by maturation (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004).

Accepting these assumptions, the first phase of accelerated window of adaptation to training is dependent on chronological age, while the second phase is related to maturation/PHV and therefore the timing would vary individually. However, cross sectional studies supporting this theory are scarce and results conflicting. The development of sprint performance with regard to chronological age was reported until the age of 15 in sedentary boys (Papaikovou et al., 2009). Unfortunately, the participants' maturation was not assessed and therefore only limited information about sprint development with regard to maturation can be surmised. Two other studies (Philippaerts et al., 2006; Yagüe & De La Fuente, 1998) were able to provide sprint performance data with regard to maturation of the participants, but reported conflicting results. While Yagüe and de la Fuente (1998) stated that the highest improvements in a 40 metre dash occurred 16 months prior to and 12 months post-PHV (Yagüe & De La Fuente, 1998), Philippaerts (2006) reported no improvements 18 months prior to PHV and the most improvements in sprint performance from 12 to 6 months prior PHV (Philippaerts et al., 2006) for eight participants.

Given the conjecture, this paper attempts to collate and synthesise the literature by reviewing popular sprint training methods and their effect on sprint kinetics and kinematics with participants of the included studies classified by chronological age and divided into likely maturity status (pre-, mid-, and post-PHV). The method of categorisation (≤12 years of age = pre-PHV; 13-15 years of age = mid-PHV; ≥16 years of age = post-PHV) is based on the assumption that peak height velocity in European/North American population occurs around the age of 14 (Malina, Bouchard, & Bar-Or, 2004) with the onset of PHV occurring approximately one year prior the point of PHV (Tanner, 1966). Fifteen years of age as the conclusion for the "mid-PHV" category is due to the fact that participants have reached between 90-94% of their adult stature by the age of 14-15 (Malina, Bouchard et al., 2004; Malina, Cumming, Morano, Barron, & Miller, 2005). Though different, given that studies have quantified maturation in various manners (Baquet, van Praagh, & Berthoin, 2003), this approach may divide different maturity status more appropriately and provide valuable insight about different training methods and their effect on sprint variables with regard to chronological age and their likely associated maturity status. For the purposes of this review, training studies have been categorised into non-specific (strength, power and plyometric training methods) and specific sprint training forms (sprint, resisted and assisted training methods). All studies cited in the review involve male participants, and percent changes and effect sizes (ES) are calculated where possible and appropriate. Generally, the ES allows comparisons of the magnitudes of effectiveness of various methods on sprint kinetics and kinematics between studies. The negative ES based on Hopkins (2009) and presented in table 3.1 as a description of training effects will be used in this article, due to improvements in sprint performance, a decrease in sprint time, resulted in a negative ES. The purpose of the review is to quantify the effects of different training methods on sprint times in male youth.

Table 3.1. Interpretation of negative effect sizes according to Hopkins (2009)

Magnitude	ES
Trivial	< -0.20
Small	≤ -0.20 > -0.60
Moderate	≤ -0.60 > -1.20
Large	≤ -1.20 > -2.00
Very Large	≤ -2.00 > -4.00
Nearly Perfect	< -4.00

3.3 Methods

To obtain articles for the data analysis, a computer search of PubMed, Google Scholar, Sport Discus and Medline was conducted. The search terms used as separate words or in combination with each other for the “title”, “keywords” and “in-text search” were: “sprint”, “sprinting”, “acceleration”, “velocity”, “running”, “power”, “speed”, “agility”, “youth”, “maturation”, “peak height velocity”, “pubescent”, “effect of”, “resisted”, “assisted”, “downhill”, “uphill”, “treadmill”, “non-motorised”, “torque”, “plyometric”, “strength”, “coordination”, “training”, “children”, “performance”, “speed” and “skills”. The bibliographies of all reviewed articles were then searched and also reviewed. Studies were chosen if they fulfilled the following seven selection criteria: (a) the study used a training method described earlier as non-specific or specific; (b) the study detailed the duration of the training and the training frequency per week; (c) the study clearly detailed the outcome measures of interest (e.g. 10 metre sprint time); (d) the study gave detailed information about male participants characteristics (i.e. age, height, mass, training status, including standard deviations); (e) the study presented group means and standard deviations for the dependant variable before and after training; (f) studies were published before January 2011; and (g) studies had to be written in the English language and must have been published as a full text article in a peer-review journal. The following characteristics were recorded for all articles: Author, year, sample size, age, training status, maturation, training methods, total amount of training sessions, number of weeks of training intervention, number of sessions per week, testing distance, training effect in percent change and effect size.

3.4 Results

The included studies (N = 17) represented 608 participants. Their age ranged from 11-17 with an average age of 12.51 (± 0.76 years), height of 1.56 (± 0.21 m), and mass of 52.28 (± 6.47 kg). The total effect sizes grouped for all maturity status were -0.57 (± 0.31), -0.56 (± 1.26), -0.41 (± 0.58) and -0.96 (± 0.13) for sprinting-, plyometric-, strength- and combined-training method respectively. Percent changes were -3.47 (± 1.27), -1.07 (± 1.69), -1.95 (± 3.03) and -2.67 (± 0.67) for sprinting-, plyometric-, strength- and combined-training methods respectively. Therefore, qualitative inferences for the effect sizes for different training methods ranged from "small" to "nearly perfect". The results from the included articles for specific, non-specific and combined training methods, categorised into pre-, mid-, and post-PHV can be observed in table 3.2.

Table 3.2. Percent changes and effect size for training methods with regard to maturity status of the participants

			Specific	**Non-specific**		
			Sprinting	*Plyometric*	*Strength*	*Combined*
		#studies	2	2		2
		n	67	70		35
		age (years)	11.1 ± 0.50	11.3 ± 0.49		11.8 ± 0.35
Age 8-12	pre-PHV	height (m)	1.56 ± 0.07	1.56 ± 0.06		1.53 ± 0.07
		mass (kg)	48.7 ± 7.06	48.4 ± 6.94		46.0 ± 8.86
		ES	-0.57 ± 0.31	-1.46 ± 1.85		-0.52 ± 0.13
		% Δ	-3.47 ± 1.27	-2.83 ± 0.50		-2.67 ± 0.67
		#studies		1	3	1
		n		14	106	13
		age (years)		13.3 ± 0.60	13.6 ± 0.6	13.4 ± 0.90
Age 13-15	mid-PHV	height (m)		1.59 ± 0.09	1.64 ± 0.08	1.64 ± 0.10
		mass (kg)		48.6 ± 9.60	52.3 ± 7.67	61.5 ± 21.80
		ES		-0.57 ±	-0.30 ± 0.63	0.00 ±
		% Δ		-2.04 ±	-1.46 ± 2.42	0.00 ±
		#studies		1	3	2
		n		56	201	46
		age (years)		17.3 ± 0.40	16.8 ± 1.01	17.3 ± 0.73
Age ≥16	post-PHV	height (m)		1.78 ± 0.05	1.70 ± 0.07	1.76 ± 0.14
		mass (kg)		68.7 ± 5.60	74.2 ± 8.01	71.1 ± 6.45
		ES		0.01 ± 0.24	-0.48 ± 0.56	-1.33 ± 0.47
		% Δ		0.15 ± 1.06	-2.26 ± 3.44	-5.79 ± 2.54

3.4.1 Specific sprint training forms

3.4.1.1 Sprint training

Sprint training in this section consisted of straight line sprinting with passive recovery after each all-out effort. To our knowledge there are only two studies that fulfill our inclusion criteria, which have investigated the effect of sprint training on sprint performance in youth (Kotzamanidis, 2003; Venturelli, Bishop, & Pettene, 2008). The two studies included in this section involved 67 subjects all in pre-PHV stage with an average age of 11.1 years (± 0.50), an average height of 1.56 metres (± 0.07) and an average mass of 48.65 kg (± 7.06). Ten and twelve weeks of sprint training with a training frequency of twice per week for a total number of twenty (Kotzamanidis, 2003) and twenty-four (Venturelli et al., 2008) training sessions, resulted in significantly ($p < 0.05$) improved sprint performance (10, 20 and 30 metre sprint time). Small averaged ES (-0.57 ± 0.31) and an average percent change of -3.47 (± 1.27) were observed for the included studies.The studies included for sprint training can be observed in table 3.3.

Table 3.3. Sprint training studies in male youth

Authors	**Subject No**	**Population** (age, training status)	**Training** sessions/week(#), duration (weeks), tot amount (#)	**Outcome measures**	**Training effect** (%change)	**Effect size**	**Qualitative inference**
Pre-PHV population							
Kotzamanidis (2003)	15	11.1 (± 0.5), non-athletic boys	2, 10, 20	0-20 metre	-3.66	-0.58	Small
Kotzamanidis (2003)	15	11.1 (± 0.5), non-athletic boys	2, 10, 20	0- 30 metre	-3.30	-0.41	Small
Kotzamanidis (2003)	15	11.1 (± 0.5), non-athletic boys	2, 10, 20	Flying 10-20 metre	-5.52	-0.82	Moderate
Kotzamanidis (2003)	15	11.1 (± 0.5), non-athletic boys	2, 10, 20	Flying 20-30 metre	-2.45	-0.12	Trivial
Venturelli (2008)	7	11 (± 0.5), soccer players from prof. club	2, 12, 24	0-20 metre	-2.40	-0.90	Moderate

3.4.1.2 Resisted sprint training

The term resisted sprint training is used to describe every form of sprint training in which any form of resistance is applied to an athlete whilst sprinting. Uphill sprinting is part of resisted sprint running, as well as non-motorised treadmill sprinting, or sprinting utilising weighted sleds, vests/belts, or limb weights. However, there was no literature found that satisfied the inclusion criteria of this paper on the effects of resisted sprint training on kinetic and kinematic sprint variables in youth population.

3.4.1.3 Assisted sprint training

Supramaximal or overspeed running are different terms describing assisted running. The athletes are forced to run at a higher pace than they are able to reach and maintain unassisted. Different forms of assisted sprint training exist, i.e. downhill running, towing of athletes and high speed treadmill sprinting. Unfortunately, to our knowledge there is no study investigating the effect of assisted sprint training on sprint variables in youth.

3.4.2 Non-specific sprint training forms

3.4.2.1 Strength and power training

Strength and power training in this section is referred to as resistance training using body weight or additional external weights. Six studies (Chelly et al., 2009; Christou et al., 2006; Coutts, Murphy, & Dascombe, 2004; Faigenbaum et al., 2007; Kotzamanidis, Chatzopoulos, Michailidis, Papalakovou, & Patikas, 2005; Wong, Chamari, & Wisloff, 2010) were included for analysis in this section, which consisted of a total of 307 male athletes with an average age of 15.67 years (± 0.87), height of 1.68 metres (± 0.07), mass of 66.63 kg (± 7.89). Training programs consisted of durations between 6-13 weeks with a training frequency of 2-3 times/week and therefore a total of 12-39 training sessions. Averaged effect sizes for all interventions were small (-0.41 ± 0.58) for the training programs used in the studies. Combined %changes of -1.95% (± 3.03) were found for all the studies. With regard to the maturation of the participants it needs to be mentioned that only training studies using mid- and post-PHV participants fulfilled the inclusion criteria of the literature review. Therefore, the effect of strength training on pre-PHV participants on sprint performance is not presented in this review. However, it was possible to calculate effects sizes and percent changes from pre- to post-testing for mid- and post PHV participants (see table 3.4). Generally, the effect of strength training in youth athletes was more consistent in post-PHV as two cases for mid-PHV populations failed to report significant improvements (N = 32, ES = 0.30 ±

0.28, %change = 0.90 ± 0.89) in sprint performance while two other studies reported improvements after strength training (N = 74, ES = -0.74 ± 0.35, %change = -3.24 ± 1.17). Interestingly, the trivial ES were associated with training durations of 6-8 weeks, whereas the greater training effects were associated with training durations between 12-16 weeks. Coincidentally, the ES increased with increasing training duration for the mid-PHV population while 12 weeks training seemed to be most efficient for the post-PHV participants. With regard to the effect of sprint training on different sprint distances, it can be stated that 20 metre and 30 metre sprint distances were the most affected distances in post- and mid-PHV participants respectively. All the studies included in understanding the effects of strength and power training can be observed in table 3.4.

Table 3.4. Strength and power training studies in male youth

Authors	**Subject No**	**Population** (age, training status)	**Training** sessions/week (#), duration (weeks), total amount (#)	**Outcome measures**	**Training effect** (%change)	**Effect size**	**Qualitative inference**
Mid-PHV population							
Christou et al. (2006)	9	13.8 (± 0.4), soccer players	2, 16, 32	0-30 metre	-2.56	-0.81	Moderate
Christou et al. (2006)	9	13.8 (± 0.4), soccer players	2, 8, 16	0-30 metre	1.78	0.56	None
Faigenbaum (2007)	14	13.6 (± 0.7), healthy & active boys	2, 6, 12	0-9.1 metre	0.00	0.00	Trivial
Wong et al. (2010)	28	13.5 (± 0.7), regional representative soccer players	2, 12, 24	0-30 metre	-2.27	-0.32	Small
Post-PHV population							
Chelly et al. (2009)	11	17.0 (± 0.3), post-pubertal junior soccer players	2, 8, 16	0-5 metre	-6.99	-1.43	Large
Chelly et al. (2009)	11	17.0 (± 0.3), post-pubertal junior soccer players	2, 8, 16	35 – 40 metre	-10.94	-1.75	Large
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, supervised	3, 12, 36	0-10 metre	-0.93	-0.25	Trivial
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, unsupervised	3, 12, 36	0-10 metre	-0.93	-0.22	Moderate
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players supervised	3, 12, 36	0-20 metre	-0.87	-0.37	Small
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, unsupervised	3, 12, 36	0-20 metre	-1.15	-0.36	Small
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, supervised	3, 6, 18	0-10 metre	-0.93	-0.25	Trivial
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, unsupervised	3, 6, 18	0-10 metre	-0.47	-0.11	Trivial
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, supervised	3, 6, 18	0-20 metre	-0.29	-0.12	Trivial
Coutts et al. (2004)	21	16.6 (± 1.2), healthy & young rugby players, unsupervised	3, 6, 18	0-20 metre	-0.86	-0.27	Small
Kotzamanidis et al. (2005)	11	17.1 (± 1.1), soccer players	39, 13, 3	0-30 metre	-0.46	-0.12	Trivial

3.4.2.2 Plyometric training

Plyometric training can be referred to as jump training, and for the subjects involved in this review, it mostly included jumping, hurdling, skipping and bouncing. Plyometric training programs were used in 10-17 year olds (Diallo, Dore, Duche, & van Praagh, 2001; Kotzamanidis, 2006; Meylan & Malatesta, 2009; Thomas, French, & Hayes, 2009) to investigate their effect on sprint performance. Data for pre-, mid-, and post-PHV populations were calculated from four studies (N = 140), with an average age of 13.89 years (± 0.46), an average height of 1.65 metre (± 0.06) and an average mass of 56.54 kg (± 6.67). Training programs were between 6-10 weeks in duration and with a training frequency of 1-3 times/week and therefore a total of 10-30 training sessions. The averaged ES for the sample was -0.56 (± 1.26) with %changes of -1.07 (± 1.69) in sprint times. From the total pool of 140 participants, 70 (age = 11.27 ± 0.49 years, height = 1.56 ± 0.06 metre, mass = 48.40 ± 6.94 kg) were categorised into pre-PHV stage, 14 (age = 13.30 ± 0.60 years, height = 1.59 ± 0.09 metre, mass = 48.60 ± 9.60 kg) were classified as mid-PHV and the remaining 56 (age = 17.30 ± 0.40 years, height = 1.78 ± 0.05 metre, mass = 68.70 ± 5.60 kg) as post-PHV.

A six to ten week training program improved 10 (Meylan & Malatesta, 2009), 20 (Diallo et al., 2001; Kotzamanidis, 2006; Thomas et al., 2009) and 30 metre (Kotzamanidis, 2006) sprint performance significantly. With regard to training effect of plyometric training on different sprint distances, it can be surmised that ES nearly increased consistently with increasing distance. Values were 0.24, -0.18, -0.16, -0.61, -4.67 for 5, 10, 15, 20 and 30 metre distance respectively. All studies included in this section on plyometric training are detailed in table 3.5.

Table 3.5. Plyometric training studies in male youth

Authors	**Subject No**	**Population** (age, training status)	**Training** sessions/week(#), duration (weeks), total amount (#)	**Outcome measures**	**Training effect** (%change)	**Effect size**	**Qualitative inference**
Pre-PHV population							
Diallo et al. (2001)	10	12.3 (± 0.4), soccer players	3, 10, 30	20 metre	-2.78	-1.43	Large
Kotzamanidis (2006)	15	11.1 (± 0.5), healthy untrained prepubertal boys	1, 10, 10	10 metre	-2.23	-0.50	Small
Kotzamanidis (2006)	15	11.1 (± 0.5), healthy untrained prepubertal boys	1, 10, 10	10-20 metre	-3.51	-0.55	Small
Kotzamanidis (2006)	15	11.1 (± 0.5), healthy untrained prepubertal boys	1, 10, 10	20-30 metre	-3.11	-0.19	Trivial
Kotzamanidis (2006)	15	11.1 (± 0.5), healthy untrained prepubertal boys	1, 10, 10	30 metre	-2.52	-4.67	Nearly perfect
Mid-PHV population							
Meylan & Malatesta (2009)	14	13.3 (± 0.6), soccer players	2, 8,16	10 metre	-2.04	-0.57	Small
Post-PHV population							
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, drop-jump group	2, 6,12	5 metre	0.33	1.94	Negative
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, countermovement-jump group	2, 6,12	5 metre	0.14	0.94	Negative
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, drop-jump group	2, 6,12	10 metre	0.33	1.14	Negative
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, countermovement-jump group	2, 6,12	10 metre	0.00	0.00	Negative
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, drop-jump group	2, 6,12	15 metre	-0.14	-0.41	Trivial
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, countermovement-jump group	2, 6,12	15 metre	-0.18	-0.79	Trivial
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, drop-jump group	2, 6,12	20 metre	-0.27	-0.97	Small
Thomas et al. (2009)	56	17.3 (± 0.4), soccer players from a professional soccer academy, countermovement-jump group	2, 6,12	20 metre	-0.14	-0.63	Trivial

3.4.3 Combined training

Combined training methods referred to training that used two or more training methods. Studies included in this section utilised a non-specific method (i.e. strength training) in combination with either another non-specific method (i.e. plyometric) or a specific sprint training form (i.e. sprinting). A total of 6 studies (Faigenbaum et al., 2007; Ingle, Sleap, & Tolfrey, 2006; Kotzamanidis et al., 2005; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010; Tsimahidis et al., 2010; Venturelli et al., 2008) utilised combined training of which five studies across different maturity status' are included in this section. The five studies involved 94 subjects with an average age of 14.7 years (± 0.61), an average height of 1.66 m (± 0.11) and an average mass of 60.4 kg (± 9.47). Thirty five participants were categorised into pre-PHV status (age = 11.82 ± 0.35 years, height = 1.53 ± 0.07 metre, mass = 46.00 ± 8.86 kg), 13 participants into mid-PHV status (age = 13.40 ± 0.90 years, height = 1.64 ± 0.10 metre, mass = 61.50 ± 21.80 kg) and the remaining 46 into post-PHV status (age = 17.30 ± 0.73 years, height = 1.76 ± 0.14 metre, mass = 71.13 ± 6.45 kg). Average effect sizes and %change for the pre-PHV group was -0.52 (± 0.13) and -2.67% (± 0.67), 0.00 and 0.00% for the mid-PHV group and -1.33 (± 0.47) and -5.79% (± 2.54) for the post-PHV group respectively. Duration of training ranged from 6-13 weeks, training frequencies of 1-3 sessions per week and a total of 6-39 sessions of strength training in combination with ballistic (Maio Alves et al., 2010), power (Mujika, Santisteban, & Castagna, 2009), sprint (Chelly et al., 2009; Kotzamanidis et al., 2005), plyometric (Faigenbaum et al., 2007; Ingle et al., 2006) and high-speed coordination training (Venturelli et al., 2008) improved sprint distance of 0-5 (Chelly et al., 2009; Maio Alves et al., 2010), 0-9.1 (Faigenbaum et al., 2007), 0-15 (Maio Alves et al., 2010; Mujika et al., 2009), 0-20 (Venturelli et al., 2008), 0-30 (Kotzamanidis et al., 2005), and 0-40 (Ingle et al., 2006) metres significantly. Improvements were “moderate”, “trivial” and “moderate” to “large” for pre-PHV, mid-PHV and post-PHV participants respectively. With regard to training efficacy on different distances in different maturity categories, it can be stated that combined training methods had more effect on shorter distances in pre- and post-PHV participants. ES for 20 and 40 metres were -0.62 and -0.43 for pre-PHV participants and -1.59, -1.30, and -0.88 for 5, 15, and 30 metres in post-PHV participants respectively.

Unfortunately, only one study (Ingle et al., 2006) reported the maturation of the participants, with all participants grouped into pubic hair stage 1 and 2 for genital development. According to Malina et al. (2004), stages 1 and 2 for pubic hair is an equivalent index of maturation compared to pre-PHV status, with most of the boys (87%) reaching PHV at pubic hair stage 3-5. Therefore participants in the study of Ingle et al. (2006) were grouped into pre-PHV status. A 12 week training period of combined strength and plyometric training improved 40 metre sprint performance of pre-PHV male participants. Table 3.6 presents the included studies for this section on combined training methods.

Table 3.6. Combined method training studies in male youth

Authors	**Subject No**	**Population** (age, training status)	**Training** sessions/week(#), duration (weeks), total amount (#)	**Outcome measures**	**Training effect** (%change)	**Effect size**	**Qualitative inferences**
Pre-PHV population							
Ingle et al. (2006	26	11.82 (± 0.35), boys from a local school	3, 12, 36	0-40 metre	-3.15	-0.43	Small
Venturelli (2008)	9	11 (± 0.5), soccer players from prof. club	2, 12,24	0-20 metre	-2.20	-0.62	Moderate
Mid-PHV population							
Faigenbaum et al. (2007)	13	13.4 (± 0.9), healthy and active boys	2, 6, 12	0-9.1 metre	0.00	0.00	Trivial
Post-PHV population							
Kotzamanidis et al. (2005)	12	17.0 (± 1.1), recreational soccer players	3, 13, 39	0-30 metre	-3.46	-0.88	Moderate
Maio & Alves (2010)	8	17.4 (± 0.6), elite Portuguese soccer players	2, 6,12	0-5 metre	-6.19	-1.75	Large
Maio & Alves (2010)	8	17.4 (± 0.6), elite Portuguese soccer players	2, 6,12	0-15 metre	-3.11	-0.80	Moderate
Maio & Alves (2010)	9	17.4 (± 0.6), elite Portuguese soccer players	1, 6, 6	0-5 metre	-9.17	-1.43	Large
Maio & Alves (2010)	9	17.4 (± 0.6), elite Portuguese soccer players	1, 6, 6	0-15 metre	-7.03	-1.80	Large

3.5 Discussion and conclusions

This paper reviewed all non-specific and specific sprint training methods and their training effects on overground sprinting in youth. Based on the averaged ES derived from all studies for each training method grouped by maturity status the following tentative conclusions are made:

Pre-PHV: Plyometric training (Diallo et al., 2001; Kotzamanidis, 2006) was the most effective training method for improving sprint times in pre-PHV participants (ES = -1.46 ± 1.85, %change = -2.83 ± 0.50), followed by sprint training (Kotzamanidis, 2003; Venturelli et al., 2008) (ES = -0.57 ± 0.31, %change = -3.47 ± 1.27) and combined (Ingle et al., 2006; Venturelli et al., 2008) (ES = -0.52 ± 0.13, %change = -2.67 ± 0.67) training methods. The effect of resisted, assisted and strength and power, training on sprint times in pre-PHV participants is unknown.

Mid-PHV: Plyometric training methods (Meylan & Malatesta, 2009) were the most effective training in mid-PHV participants (ES = -0.57, %change = -2.04) followed by strength (Christou et al., 2006; Faigenbaum et al., 2007; Wong et al., 2010) (ES = -0.30 ± 0.63, %change = -1.46 ± 2.42) and combined (Faigenbaum et al., 2007) training (ES = 0.00, %change = 0.00). Specific sprint training studies in mid-PHV participants were not found throughout the literature, which results in a lack of knowledge in this area.

Post-PHV: Post-PHV participants sprint times benefitted most from combined training methods (Kotzamanidis et al., 2005; Maio Alves et al., 2010) (ES = -1.33 ± 0.47, %change = -5.79 ± 2.54) followed by strength training (Chelly et al., 2009; Coutts et al., 2004; Kotzamanidis et al., 2005) (ES = -0.48 ± 0.58, %change = -2.26 ± 3.44). Figure 3.1 and figure 3.2 illustrate and summarise the combined effect sizes and percent changes for all training methods and maturity status.

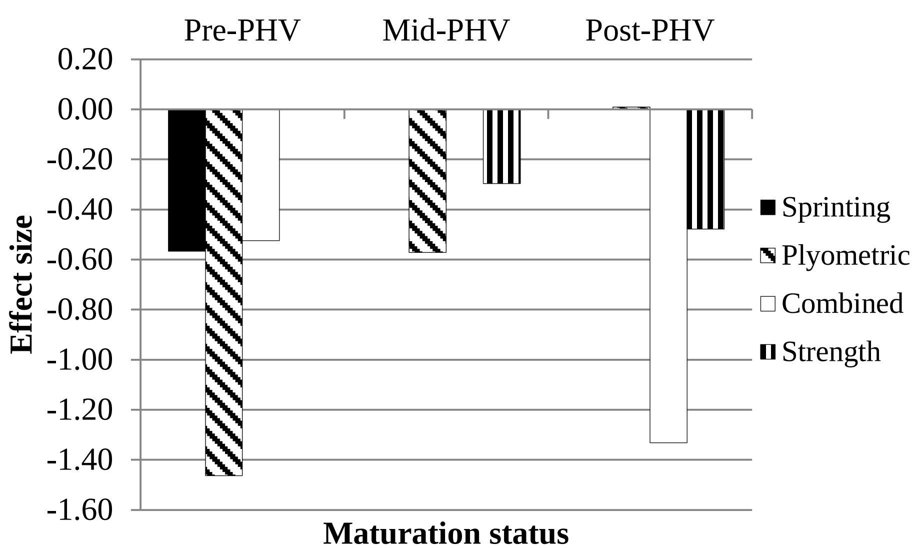

Figure 3.1. Combined effect sizes for all training methods with regards to maturation

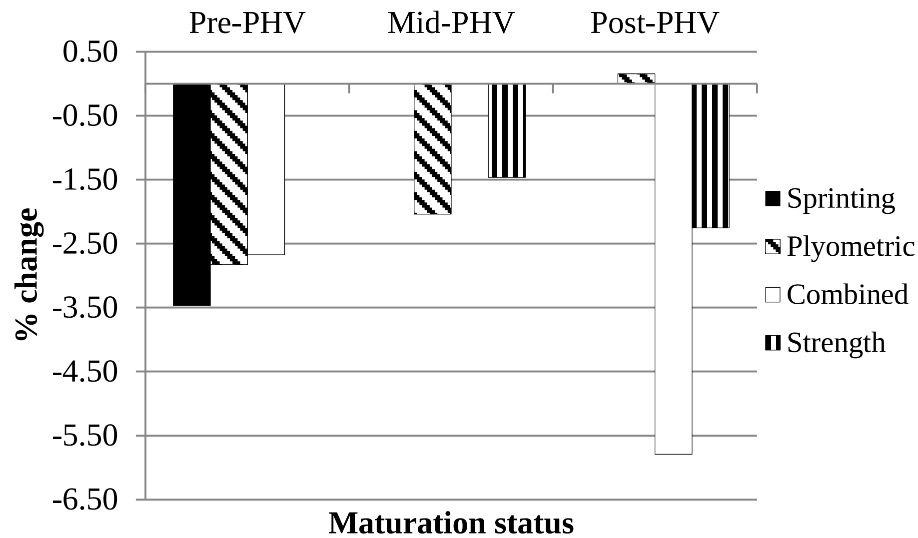

Figure 3.2. Combined percent changes for all training methods with regards to maturation

However, as can be observed from the tables, information about the magnitude of training volume that leads to changes in sprint time is sparse; therefore making definitive conclusions regarding minimal and optimal training loads for each maturity status for specific and non-specific training forms is problematic. As a result from this treatise of the literature in this area, there is a great deal more research needed. Basing training theory (e.g. windows of trainability) on the number of papers and samples sizes reviewed in this paper is somewhat tenuous and more longitudinal studies are needed for all training methods in all maturity groups. Furthermore, it is difficult to quantify the effects of different training methods with regard to maturation on sprint times if certain training methods have not been used in that maturity group e.g. resisted training on pre-PHV participants.

It may be that the development of sprint speed is based on so many factors that it will be extremely difficult to identify stages of development where improved performance will be optimised by training. It may be more worthwhile to concentrate research efforts on the effects of different training methods on additional variables (i.e. stride length, stride frequency, horizontal force, etc.) to better determine the development of sprint speed. Accordingly, a more in-depth analysis of sprinting performance, i.e. step-by-step analysis of kinetics and kinematics in addition and relation to split-times, after non-specific and specific training methods are needed to better define changes in sprint performance and allocate those changes to different distances (first-step vs. acceleration vs. maximum velocity phase) in youth populations. Finally, dedicated measurements of maturation (i.e. age at peak height velocity) need to be included in future measurement of youth populations to better understand adaptation and training for speed throughout the athletes' development.

Chapter 4

Sprint running kinematics and kinetics in pre-peak-height-velocity male children on a non-motorised treadmill: reliability and normative data

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Sprint running kinematics and kinetics in pre-peak-height-velocity male children on a non-motorised treadmill: Reliability and normative data. *Sports Biomechanics*, - paper under 2nd review.

4.1 Prelude

The most basic determinants of sprint running speed are step length and step frequency. Maximising both will therefore increase velocity. However, step length and step frequency are influenced by multiple variables, which are kinetic or kinematic in nature. In order to disentangle the relative importance of these kinetic and kinematic variables as determinants of sprint running performance, advanced technology such as force plates are needed. In-ground force plates, force treadmills and non-motorised treadmills are able to quantify those kinematic and kinetic variables of interest and furthermore enable a step-by-step analysis of sprint performance. However, it would seem impractical to utilise such dynamometry on youth populations if large within subject variability is associated with the variables of interest. Therefore, the purpose of this study is to quantify the reliability of kinematic and kinetic variables associated with sprinting on a non-motorised treadmill using a sample of pre-pubescent athletes.

4.2 Introduction

Speed is an important component of athletic performance and therefore its training and monitoring is crucial in the training process and the development of the athlete. Common devices to measure sprint times are stopwatches and timing gates, which are widely used in both adult (Cronin, Green, Levin, Brughelli, & Frost, 2007; Cronin, Ogden, Lawton, & Brughelli, 2007; Kotzamanidis, Chatzopoulos, Michailidis, Papalakovou, & Patikas, 2005; Little & Williams, 2005; Sassi et al., 2009; Slawinski et al., 2010) and paediatric populations (Babel, Hertogh, & Hue, 2005; Kotzamanidis, 2003, 2006; Le Gall, Beillot, & Rochcongar, 2002; Lidor et al., 2005; Spamer, 2000; Tumilty, 2000; Wong, Chamari, Dellal, & Wisløff, 2009; Wong, Chamari, & Wisloff, 2010). Both devices quantify the time needed to complete certain distances, from which additional variables such as average speed or split times can be calculated. The reliability associated with sprint timing between 5-40 m is well documented for both adult (Cronin, Green et al., 2007; Gabbett, 2002; Little & Williams, 2006; Wilson, Newton, Murphy, & Humphries, 1993) and youth (Christou et al., 2006; Drinkwater, Hopkins, McKenna, Hunt, & Pyne, 2007;

Gabbett, 2002; Kotzamanidis, 2003, 2006; Kotzamanidis et al., 2005; Kruger & Pienaar, 2009) populations utilising timing gates. Intra- and inter-day values of coefficient of variation (CV) for sprinting distances of 10, 20, 30 and 40 metres ranged from 0.83% - 2.07% (Christou et al., 2006; Gabbett, 2002). Intra- and inter-day intraclass correlation coefficients (ICC) ranged from 0.88 and 0.98 for 10-40 metres (Christou et al., 2006; Gabbett, 2002; Kotzamanidis, 2006) and Pearson correlation coefficient from 0.90-0.97 (Kotzamanidis, 2003, 2006; Kotzamanidis et al., 2005; Kruger & Pienaar, 2009) for youth.

Whilst very reliable, timing gates provide very little information on sprint kinematics and kinetics. Measuring running mechanics in a field setting provides several methodological difficulties and therefore the utilisation of torque and non-motorised treadmills, which allow the measurement of kinematics and kinetics associated with sprint performance, have been used in adults (Brughelli, Cronin, & Chaouachi, 2011; Chia & Lim, 2008; Hughes, Doherty, Tong, & Cable, 2005; Jaskólska, Gossens, Veenstra, Jaskólski, & Skinner, 1999; Jaskólski, Veenstra, Goossens, Jaskólska, & Skinner, 1996; Lim & Chia, 2007; Ross et al., 2009; Sirotic & Coutts, 2008) and youth (Bloxham, Welsman, & Armstrong, 2005; Chelly & Denis, 2001; Falk et al., 1996; Oliver, Armstrong, & Williams, 2009; Oliver, Williams, & Armstrong, 2006; Oliver, Armstrong, & Williams, 2007; Ratel, Williams, Oliver, & Armstrong, 2004; Ratel, Williams, Oliver, & Armstrong, 2006; Sutton, Childs, Bar-Or, & Armstrong, 2000; Yanagiya, Kanehisa, Kouzaki, Kawakami, & Fukunaga, 2003) populations. Inter-day ICC reliability of peak and mean power of a paediatric population performing a 30-second sprint on a torque treadmill (Falk et al., 1996) has been reported as 0.80 and 0.81 respectively. Using a similar protocol, Sutton et al. (2000) reported absolute values of mean (15.3 Watts) and peak (26.6 Watts) power as a coefficient of repeatability of children on a torque treadmill. Inter-day CVs of adolescents in a 5-second all out sprint on a non-motorised treadmill were 2.88 and 8.32% for mean and peak velocity respectively (Oliver et al., 2006).

Cross sectional studies examining children on a non-motorised treadmill are sparse. Only short term power output has been examined, the correlation coefficients of the treadmill test with a Wingate 30 s Bicycle Test were 0.82 and 0.88 for mean and peak power (Sutton et al., 2000). As can be observed from the literature reviewed, the assessment of youth using diagnostic treadmills is for the most part unexplored. Furthermore, what little research there is has focused on power and velocity outputs. Modern non-motorised treadmills can quantify many additional kinetic and kinematic variables (i.e. horizontal and vertical force, step frequency/length, work and leg asymmetries), which could give better insight into the mechanical determinants of sprint performance. However, it would seem impractical to utilise such dynamometry on youth populations if large within subject variability is associated with the variables of interest. Furthermore, it has been shown that younger and less mature youth displayed poorer motor competency compared to older and more mature peers (Gerodimos et al., 2008), therefore the purpose of this study was to quantify the reliability of kinematic and kinetic variables and to present normative data of those variables using a sample of pre-peak-height-velocity (PHV) male athletes sprinting on a non-motorised treadmill.

4.3 Methods

4.3.1 Participants

Twenty-five athletic male children between 8 and 13 years of age volunteered to participate in this study. All participants were physically active in team sports or track and field running disciplines, trained a minimum of two times per week in their sport and represented their club and/or school on a regional and/or national level. Mean age, height, weight and maturation offset were 10.4 ±1.37 years, 141 ± 6.56 centimeters, 34.0 ± 4.91 kg and -2.86 ± 0.84 years from PHV respectively. All participants and their legal guardians were informed of risks and benefits of participation in the research and both, legal guardians and participants, provided written informed consent and assent to participate in this study. Procedures were approved by the institutional Ethics Committee of AUT University.

4.3.2 Equipment

Sprint performance was assessed using a non-motorised force treadmill (Woodway, Germany). The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), which measured horizontal force. The load cell was adjusted accordingly to the subject's height, so that the tether was horizontal during testing. Four individual load cells that were mounted underneath the running surface measured vertical force. The entire system was calibrated before each session using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), and analysed with the Pacer Performance software (Fitness Technology, Australia).

4.3.3 Procedures

Participants were assessed on three separate occasions, with 3-7 days between assessments. Data were collected at the same time of day and activity patterns in the 48 hours prior to each data collection session were standardised around mode of training and daily structure. On the first day of testing, anthropometric measurements were taken before the familiarisation session. The height (cm), sitting height (cm), weight (kg) was measured and the body mass index (BMI) calculated. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al. (2002): Maturity Offset = -9.236 + (0.0002708 * Leg Length * Sitting Height) + (-0.001663 * Age *

Leg Length) + (0.007216 * Age * Sitting Height) + (0.02292 * Weight by Height Ratio). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. Participants were categorised into three groups as followed: pre-PHV velocity (-3 years to -1 years from PHV), around PHV (-1 to +1 years from PHV) and post-PHV (+1 to +3 years from PHV) similar to to the procedures of Rumpf et al. (2012). The standard error of estimate for PHV is 0.49 years for boys (Mirwald et al., 2002).

Participants then completed a familiarisationation session on the non-motorised treadmill, which consisted of standing, walking and running at a self-chosen speed. The familiarisation phase was also taken as a warm-up phase (~5 minutes) if the participants felt safe and were able to perform runs without using their hands holding on to the frame of the treadmill. If the participants were unable to run freely, the first day of data collection was postponed. Otherwise, a series of warm-up sprints on the treadmill, i.e. 3 x 5 seconds, proceeded the initial testing. Three sprints from a standing position with a duration of five seconds followed. The participants were allowed to recover completely (four minutes) after each trial. The same procedures, without the inclusion of the anthropometric assessments, were replicated on testing occasions two and three.

4.3.4 Data analysis

Vertical and horizontal forces and running velocities were measured directly via the load cells and the speed photomicrosensors. Average step length (distance covered with one step), average step frequency (number of footfalls per second), average and peak power (horizontal force * velocity) and average work (horizontal force * displacement) were calculated and all variables were detailed in the report sheet of the software. The mean over all steps recognised by the software was taken for further statistical analysis.

4.3.5 Statistical analysis

The reliability of the measures were assessed using traditional reliability statistics i.e. percent change in the mean, CV and ICC utilising customised spreadsheets (Hopkins, 2009). The mean and standard deviation (std.) were calculated for all variables. The standard error of measurement, expressed as a CV of the log transformed data, was reported to determine the absolute reliability or within subject variation of the different variables (Hopkins, 2000a) for two pairs of testing sessions, as well as the overall testing sessions. Percent change in the mean was reported to indicate the extent to which the average performance got better or worse over testing occasion due to systematic effects (e.g. learning effect) and random effects (e.g. noise) (Hopkins, 2000a). Relative reliability, which refers to the consistency of the rank or position of an athlete in relation to others, was quantified using a two-way random effect with absolute agreement ICC on the mean score of two pairs of data collection session and across all three testing sessions. The level of acceptance for reliability was a CV ≤ 10% (Atkinson & Nevill, 1998) and ICC ≥ 0.70 (Vincent, 1994).

4.4 Results

The reliability statistics and normative data of all variables of the 5-second sprint protocol can be observed in table 4.1. Mean percent changes of -1.65 to 2.30 were observed between days indicating no systematic change in these values. The CVs ranged from 0.56% (vertical force) to 8.72% (average work). There was less variability with the force measures (3.43% ± 1.31) as compared to power measures (6.21% ± 1.10) and work (7.81%). Once more there was no systematic change in the mean CVs between testing occasions.

The ICC scores for eight variables were found reliable (ICC ≥ 0.70) between days for both comparisons. However, average horizontal force were > 0.70 for one between day measurement (i.e. 1 vs. 2 or 2 vs. 3), but average vertical forces and average step rate were less than 0.70 (-0.04 – 0.69) for both between day measurements and the average across days.

Table 4.1. Intra and inter-day reliability and normative data (mean ± SD) for the 5 second sprint on the non-motorised treadmill

	Change in the mean (%) (CI)			**Coefficient of Variation (%) (CI)**			**Intraclass coefficient (%) (CI)**			**Normative data**			
Variable	**Day 1-2**	**Day 2-3**	**Mean**	**Day 1-2**	**Day 2-3**	**Mean**	**Day 1-2**	**Day 2-3**	**Mean**	**Day 1**	**Day 2**	**Day 3**	**Mean**
Average velocity (m/s)	**0.61** (-2.30 ± 3.61)	**0.91** (-2.75 ± 4.71)	**0.76**	**3.78** (2.73 ± 5.95)	**4.78** (3.45 ± 7.55)	**4.31** (3.31 ± 6.17)	**0.89** (0.71 ± 0.96)	**0.85** (0.61 ± 0.95)	**0.88** (0.72 ± 0.95)	2.54 ± 0.29	2.55 ± 0.27	2.58 ± 0.33	**2.55 ± 0.29**
Peak velocity (m/s)	**-0.29** (-2.25 ± 1.70)	**1.26** (-1.54 ± 4.14)	**0.48**	**2.54** (1.84 ± 3.98)	**3.61** (2.61 ± 5.68)	**3.12** (2.40 ± 4.45)	**0.96** (0.87 ± 0.98)	**0.92** (0.77 ± 0.97)	**0.94** (0.85 ± 0.98)	3.22 ± 0.37	3.21 ± 0.34	3.26 ± 0.4	**3.23 ± 0.37**
Average power (W)	**-0.63** (-4.76 ± 3.69)	**1.36** (-2.73 ± 5.61)	**0.36**	**5.52** (3.98 ± 8.73)	**5.34** (3.85 ± 8.44)	**5.43** (4.17 ± 7.80)	**0.84** (0.58 ± 0.94)	**0.87** (0.66 ± 0.96)	**0.86** (0.69 ± 0.95)	300 ± 39.3	298 ± 37.5	303 ± 46.1	**300 ± 41.0**
Peak power (W)	**-0.70** (-5.43 ± 4.27)	**0.26** (-5.36 ± 6.21)	**-0.22**	**6.36** (4.58 ± 10.1)	**7.57** (5.44 ± 12.0)	**6.99** (5.35 ± 10.1)	**0.85** (0.62 ± 0.95)	**0.81** (0.53 ± 0.93)	**0.83** (0.63 ± 0.94)	560 ± 81.9	556 ± 87.3	558 ± 91.3	**558 ± 86.8**
Average horizontal force (N)	**-0.86** (-3.01 ± 1.34)	**0.59** (-0.83 ± 2.03)	**-0.13**	**2.81** (2.03 ± 4.42)	**1.81** (1.31 ± 2.84)	**2.37** (1.82 ± 3.37)	**0.13** (-0.39 ± 0.59)	**0.69** (0.30 ± 0.88)	**0.45** (0.07 ± 0.75)	109 ± 12.7	106 ± 12.4	108 ± 14.3	**108 ± 13.2**
Peak horizontal force (N)	**-1.12** (-4.88 ± 2.79)	**0.47** (-3.54 ± 4.64)	**-0.33**	**5.03** (3.62 ± 7.94)	**5.28** (3.81 ± 8.35)	**5.16** (3.95 ± 7.39)	**0.71** (0.34 ± 0.89)	**0.71** (0.32 ± 0.89)	**0.70** (0.40 ± 0.88)	396 ± 57.8	389 ± 69.5	392 ± 62.0	**392 ± 63.1**
Average vertical force (N)	**-0.24** (-0.67 ± 0.20)	**-1.41** (-5.32 ± 2.66)	**-0.82**	**0.56** (0.40 ± 0.87)	**5.25** (3.78 ± 8.30)	**3.71** (2.85 ± 5.30)	**0.87** (0.66 ± 0.95)	**-0.04** (-0.53 ± 0.46)	**0.26** (-0.11 ± 0.63)	334 ± 52.9	326 ± 46.6	325 ± 47.4	**328 ± 49.0**
Peak vertical force (N)	**-0.33** (-2.30 ± 1.68)	**-0.13** (-1.97 ± 1.75)	**-0.23**	**2.55** (1.85 ± 4.01)	**2.38** (1.72 ± 3.73)	**2.47** (1.90 ± 3.52)	**0.75** (0.41 ± 0.91)	**0.61** (0.17 ± 0.85)	**0.71** (0.43 ± 0.88)	880 ± 193	851 ± 162	845 ± 125	**859 ± 160**
Average step rate (#/s)	**-3.66** (-8.26 ± 1.17)	**0.35** (-2.85 ± 3.66)	**-1.65**	**6.38** (4.59 ± 10.1)	**4.18** (3.02 ± 6.59)	**5.38** (4.13 ± 7.73)	**0.40** (-0.12 ± 0.75)	**0.43** (-0.08 ± 0.77)	**0.46** (0.09 ± 0.76)	4.39 ± 0.44	4.22 ± 0.24	4.23 ± 0.20	**4.28 ± 0.29**
Average step length (m)	**3.35** (-2.07 ± 9.08)	**1.25** (-3.57 ± 6.31)	**2.30**	**7.05** (5.07 ± 11.2)	**6.36** (4.58 ± 10.1)	**6.71** (5.14 ± 9.66)	**0.80** (0.50 ± 0.93)	**0.84** (0.59 ± 0.94)	**0.83** (0.62 ± 0.93)	0.63 ± 0.10	0.65 ± 0.09	0.66 ± 0.11	**0.65 ± 0.10**
Average work (J)	**1.35** (-5.14 ± 8.28)	**1.60** (-3.55 ± 7.03)	**1.47**	**8.72** (6.26 ± 13.9)	**6.80** (4.89 ± 10.8)	**7.81** (5.98 ± 11.3)	**0.75** (0.40 ± 0.91)	**0.86** (0.63 ± 0.95)	**0.81** (0.59 ± 0.93)	62.0 ± 15.6	61.2 ± 14.0	63.4 ± 17.1	**62.2 ± 15.6**

4.5 Discussion and implications

To gain a true appreciation of the reliability of a methodology, three measures should be used (Hopkins, 2000b): The percent change in the mean, the typical error of measurement (also expressed as the within subject CV) and a retest correlation (also expressed as the intraclass correlation coefficient). The percent change in the mean of variables measured directly from the force plates underneath the treadmill belt (vertical forces), the horizontal tether (horizontal forces) and the two optical photomicrosensors (belt velocity) changed less and presented smaller confidence limits as compared to computed/calculated variables, such as power (average power power), work (average work), or step length/frequency in this study. Similar findings have been reported in adults utilising a non-motorised treadmill (Brown, Hughes, & Tong, 2008; Hughes et al., 2005). However, the change in mean between testing occasions was less than 2% for all the reported variables, except for step length and step rate from day 1 to day 2, in this study. This is comparable to other studies (Brown et al., 2008; Hughes et al., 2005) that have used a non-motorised treadmill with adult populations to measure speed, force and power (change in the means from 0.2 to 3.8%). Also noteworthy was that the change in the mean was random between testing occasions indicating no systematic change in the variables of interest.

An analytical goal of the CV being 10% or below has been chosen arbitrarily by some scientists but the merits of this value are the source of conjecture (Atkinson & Nevill, 1998). All CVs were less than 10% in this study indicating the consistency of individual scores between testing occasions. These results are comparable to the non-motorised treadmill results of Oliver et al (2006) who reported CVs of 2.59 and 2.88% for mean and peak velocity (mean for the present study ~4.28% and 3.00%) and 5.41 and 8.32% for mean and peak power respectively (mean for the present study was ~5.43% and ~6.99%). Sutton et al. (2000) reported coefficients of repeatability of 26.6 W for peak power and 15.3 W for mean power, which can be recalculated to give mean CV values of 6.3 and 5.1% (Oliver et al., 2006). Once more the change in the CVs appeared random between testing occasions indicating no systematic change in the variability of the individuals' scores between the three testing occasions.

Though there are no preset standards as to what is and is not acceptable as a reliable measure, Vincent (1994) suggested that ICC values above 0.70 may be considered reliable and this index should be at least 0.90 for most clinical applications (Walmsley & Amell, 1996). Most of the variables in this study achieved acceptable ICC standards at a 0.70 threshold, however some variables (total number of steps, average step rate, average horizontal force) did not pass the 0.7 point. One reason for the relatively low ICC values in conjunction with reliable CV scores might be that participants in a homogeneous group are likely to change rank order. The inter-day

ICC values for peak (0.80) and mean power (0.81) of a paediatric population performing a 30-second sprint on a torque treadmill have been reported previously (Falk et al., 1996) and are similar to our mean (0.86) and peak (0.83) values.

4.6 Conclusion

Pre-PHV subjects were chosen in this study as it was thought that this sample would be the most likely to demonstrate high variability in the measures of interest. That is older, heavier athletes with higher motor proficiency will achieve even better reliability scores on the non-motorised treadmill. However, the results of this study were, for the most part, consistent across testing occasions and comparable to those of youth and adult populations. In this regard, using a non-motorised treadmill with youth populations does not seem problematic especially if the percent change in the mean and CV are deemed the important reliability measures. It should be realised that the Pacer performance software averaged all values over the entire length of data collection. What might also be of value is to determine the reliability at critical periods of a sprint e.g. maximum velocity. In this regard the reliability of 4-6 steps around these critical periods needs to be determined. The results of which if found reliable, could give better sprint diagnostics and inform our understanding of running mechanics and training programming to better effect.

Chapter 5

The effect of four different step detection thresholds on the kinematics and kinetics of a 30 metre sprint on a non-motorised treadmill

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. The effect of four different step detection thresholds on the kinematics and kinetics of a 30 metre sprint on a non-motorised treadmill. *Journal of Applied Biomechanics*, - paper under 2nd review.

5.1 Prelude

In the previous chapter the reliability of variables thought to be critical determinants of running sprint performance in youth were quantified. An observation from this analysis was that for some of the athletes (in particular lighter athletes) the non-motorised treadmill did not re-zero itself whilst the athlete was in flight. Such an aberration will affect the calculation of step frequency and many other variables. In order to account for that issue, the purpose of this study was to analyse the effect of different step detection thresholds on sprint kinematics and kinetics on a non-motorised treadmill.

5.2 Introduction

Running is a fundamental movement pattern of human beings and its analysis therefore of great interest to many professions. A variety of equipment has been used to quantify the kinematics and kinetics associated with running, including accelerometers (Mercer et al., 2010), cameras (Elliott & Blanksby, 1976; Frishberg, 1983; Hreljac & Stergiou, 2000; McClay & Manal, 1998; Morio, Lake, Gueguen, Rao, & Baly, 2009; Riley et al., 2008; Schache et al., 2001; Stacoff et al., 2001; Swanson & Caldwell, 2000; Wank, Frick, & Schmidtbleicher, 1998; Williams & Cavanagh, 1987) and force plates (Butler, Davis, & Hamill, 2006; Cavanagh & Lafortune, 1980; Chang, Huang, Hamerski, & Kram, 2000; Karamanidis & Arampatzis, 2005; Kerdok, Biewener, McMahon, Weyand, & Herr, 2002; Leitch, Stebbins, Paolini, & Zavatsky, 2011; Morio et al., 2009; Riley et al., 2008; Riley, Paolini, Della Croce, Paylo, & Kerrigan, 2007; Weyand, Sandell, Prime, & Bundle, 2010; Williams & Cavanagh, 1987). In terms of data collection with force plates, sampling frequencies of 200 - 2000 Hz (Butler et al., 2006; Cavanagh & Lafortune, 1980; Karamanidis & Arampatzis, 2005; Kerdok et al., 2002; Leitch et al., 2011; Morio et al., 2009; Weyand et al., 2010; Williams & Cavanagh, 1987), cut off frequencies of 30 (Morio et al., 2009; Weyand et al., 2010) or 50 Hz (Riley et al., 2007) and absolute thresholds of 10 - 150 N (Butler et al., 2006; Cavanagh & Lafortune, 1980; Chang et al., 2000; Karamanidis & Arampatzis, 2005; Leitch et al., 2011; Morio et al., 2009; Riley et al., 2008; Riley et al., 2007; Weyand et al., 2010) or relative thresholds of ~10 - 20% BM (Riley et al., 2008), or 1% of maximal vertical force values (~35 N) (Williams & Cavanagh, 1987) have been used to detect and analyse steps in adults. It appears a great variety of sampling rates, filtering methods and step detection thresholds have been used when analysing running gait in adults (Elliott & Blanksby, 1976; Frishberg, 1983; Hreljac & Stergiou, 2000; McClay & Manal, 1998; Morio et al., 2009; Riley et al., 2008; Schache et al., 2001; Stacoff et al., 2001; Swanson & Caldwell, 2000; Wank et al., 1998; Williams & Cavanagh, 1987). Furthermore the step detection threshold has been shown to impact gait results (Leitch et al., 2011), therefore is an important parameter to consider when analysing gait and running data.

As it is thought that youth and in general younger and less mature individuals present greater variability in motor skills (Gerodimos et al., 2008), it would seem important to establish reliable protocols to analyse running patterns in a youth population. This is especially so for young children, prior to their individual adolescent growth spurt, their low body mass possibly providing the greatest challenge to determine the optimal step detection threshold for the analysis of running kinematics and kinetics. However, no studies to the knowledge of these authors have investigated the step detection thresholds associated with running on a non-motorised treadmill (NMT) in a youth population. Therefore the purpose of this study was to analyse the effect of different step detection thresholds on sprint kinematics and kinetics on a NMT in a youth population.

5.3 Methods

5.3.1 Subjects

Sixteen athletes (age 10.5 ± 1.50 years, height 143 ± 6.60 cm, mass 34.8 ± 5.20 kg, maturation offset -2.90 ± 0.80 years from PHV) participated in the study. The athletes were categorised as pre-PHV, were physically active and trained a minimum of two times per week in their sport and represented their school or club at a regional and/or state level. The participants and their parents/legal guardians were informed about the potential risk involved with the study and gave written consent to participate. The investigation was approved by the ethics committee of AUT University.

5.3.2 Data acquisition and analysis

Prior to any physical testing, anthropometric measurements were taken, which included standing height (cm), sitting height (cm) and body mass (kg). Leg length was calculated by subtracting the standing height minus sitting height. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al. (2002). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset. Generally, athletes can be categorised into three groups as followed: pre-PHV velocity (-3 years to -1 years from PHV), around PHV (-1 to +1 years from PHV) and post-PHV (+1 to +3 years from PHV) (Rumpf, Cronin, Oliver, & Hughes, 2012). The standard error of estimate for PHV is 0.49 years for boys (Mirwald et al., 2002).

Participants then received a familiarisation session on the NMT (Force 3 Woodway, Wheil am Rhein, Germany), which consisted of standing, walking and running at a self-chosen speed. The familiarisation was also used as a warm-up phase (~ five minutes) if the participants felt safe and demonstrated the ability to sprint maximally on the treadmill. If the participants were unable to run maximally and without holding on to the frame of the treadmill, the data collection was postponed to another day. Otherwise, a series of warm-up sprints on the treadmill involving three five-seconds bouts preceded the testing. Three sprints of 30 metres from a split start position were then performed on the NMT. The participants were allowed to recover completely (four minutes) after each trial.

Variables of interest were collected using a sampling rate of 200 Hz utilising the Pacer Performance software (Fitness Technology, Joondalup, WA, Australia), and analysed with a custom designed Matlab (MathWorks, Inc., Natick. MA, USA) program. Each channel of data was filtered using a low pass digital Butterworth filter with zero-lag that optimised the cut off frequencies based on a residual analysis

(Winter, 2005). Vertical and horizontal forces, and running velocities were measured directly, via four individual vertical load cells that were mounted underneath the running surface, a horizontal load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), and two optical speed photomicrosensors in conjunction with a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia) respectively. All other variables were derived from the force plates, horizontal tether and/or photomicrosensors. Variables were calculated as followed:

- *Step Length:* Difference in distance from start to end of step detection threshold between alternating foot contacts.
- *Step frequency:* Number of steps per second.
- *Contact time:* Difference in time of start and end of step detection threshold.
- *Eccentric time:* Time from start of step detection threshold to zero vertical velocity. The vertical velocity was derived from the integral of the acceleration, which was derived from the maximum vertical force.
- *Aerial time:* Time outside the step detection threshold.
- *Concentric time:* Time from zero vertical velocity to end of step detection threshold.
- *Vertical displacement:* Double integration of vertical acceleration taken from maximum vertical force in the eccentric time.
- *Vertical stiffness:* Calculated from the maximum ground reaction force during contact divided by the vertical displacement of the center of mass as

described by McMahon and Cheng (1990). Vertical acceleration was obtained from the peak vertical force divided by body mass after subtracting gravitational acceleration (Cavagna, Franzetti, Heglund, & Willems, 1988).

- *Leg stiffness*: Calculated as the maximum vertical force (F_{max}) divided by the peak displacement (Δ) of the initial leg length (L) (Morin, Dalleau, Kyrolainen, Jeannin, & Belli, 2005), calculated from standing height minus sitting height:

  $$k_{leg} = F_{max} \times \Delta L^{-1}$$

  The peak displacement of the initial leg length was calculated as:

  $$\Delta L = L - \sqrt{L^2 - \left(\frac{vt_c}{2}\right)^2} + \Delta y_c$$

  where v = running velocity (in m × s^{-1}), t_c = contact time (in seconds) and Δy_c= the vertical displacement (in metres) of the center of mass when it reached its lowest point during mid-stance. Dimensionless variables for vertical and leg stiffness were derived from further multiplying the vertical stiffness with the initial leg length and then dividing the product by the participants' body mass and gravitational acceleration of 9.81 (McMahon & Cheng, 1990) .

- *Power:* Peak horizontal forces × running velocity.
- *Eccentric Power:* Power during eccentric time.

- *Concentric Power:* Power during concentric time.

Steps were identified when the force was greater (foot touchdown) or smaller (toe-off) than 10, 15, 20, or 30% of the participant's body mass (see figure 5.1). Data were than separated into right and left steps using the data from the individual force plates of the NMT. The fastest two consecutive steps for each leg were chosen and averaged for data analysis.

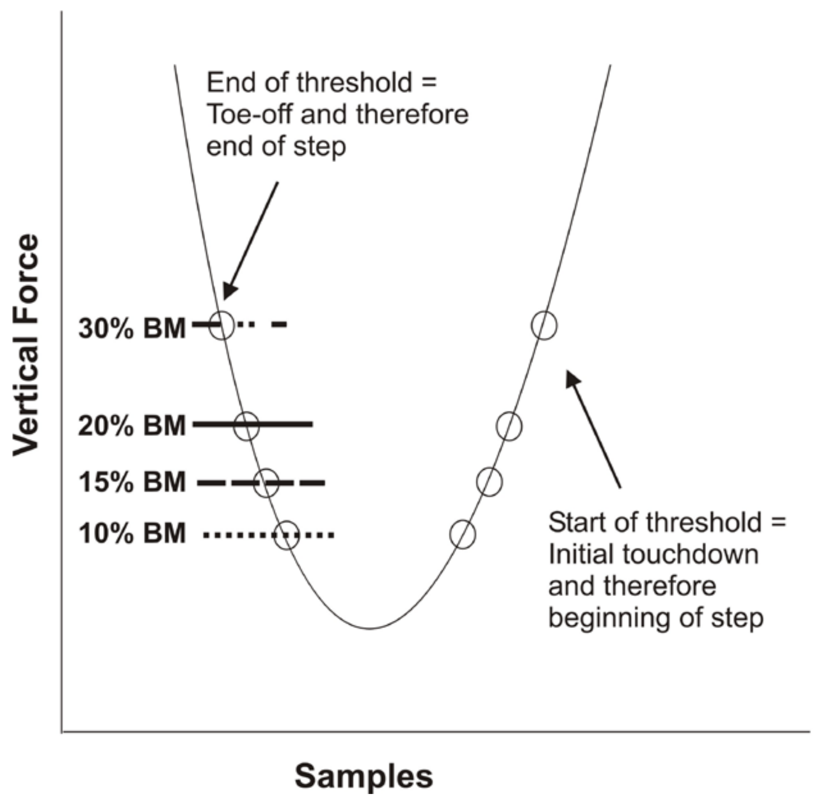

Figure 5.1. Vertical force-time graph of a step including all thresholds

5.3.3 Statistical analysis

Means and standard deviations (SD) were used as measures of centrality and spread of data. The fastest two consecutive steps for each leg of each of the three trials for each threshold were averaged for an individuals data. A repeated-measures ANOVA (SPSS, 18.0, IBM, Armonk, NY, USA) with Bonferroni post hoc contrasts was used to determine whether there was a significant difference in the four different thresholds for each variable of interest. An alpha level of $P < 0.05$ was chosen as the criterion for significance. Within-trial reliability of the three trials at the four different thresholds was quantified using a coefficient of variation (CV = SD/mean × 100).

5.4 Results

Vertical and leg stiffness decreased, whilst step length, vertical displacement, contact time, eccentric and concentric time increased significantly ($P< .05$) from 10% to the 30% BM threshold (see table 5.1). Two kinematic variables, vertical displacement and eccentric time decreased significantly from 10% to the 20% BM thresholds. Contact time was the only variable that decreased significantly from the 15 to the 30% BM threshold. The kinetic variables were for the most part not significantly affected by the magnitude of the different thresholds.

Averaged CVs across all variables for each threshold (10, 15, 20, and 30%) were 10.3, 6.10, 8.00, and 5.90% respectively. When CVs for each variable were averaged over all thresholds, only power, eccentric power, vertical and leg stiffness were greater than 10%. Generally, the CVs improved (i.e. decreased) as the threshold of detection increased.

Table 5.1. Means, standard deviations and coefficient of variation values for all variables across different thresholds

	10% BM threshold			**15% BM threshold**			**20% BM threshold**			**30% BM threshold**		
	Mean	**± Std.**	**CV**	**Mean**	**± Std.**	**CV**	**Mean**	**± Std.**	**CV**	**Mean**	**± Std.**	**CV**
Power (W)	563	± 75.4	13%	558	± 65.0	10%	529	± 66.4	13%	515	± 38.0	7%
Peak horizontal force (N)	214	± 27.2	12%	209	± 19.6	9%	202	± 23.6	13%	194	± 13.9	7%
Peak vertical force (N)	780	± 25.7	3%	777	± 27.8	4%	776	± 32.4	4%	791	± 30.5	4%
Mean eccentric power (N)	416	± 50.0	12%	420	± 33.5	8%	406	± 49.7	13%	400	± 37.4	10%
Mean concentric power (N)	510	± 48.7	9%	479	± 41.1	9%	454	± 58.3	12%	438	± 22.8	5%
Vertical stiffness	*87.6	± 20.3	14%	102	± 36.4	8%	116	± 37.3	11%	127	± 37.0	10%
Leg stiffness	*4.58	± 0.98	15%	4.81	± 1.24	8%	5.31	± 1.46	11%	5.88	± 0.54	9%
Step length (m)	*0.82	± 0.06	7%	0.77	± 0.04	5%	0.74	± 0.04	5%	0.70	± 0.03	4%
Step frequency (#steps/s)	1.96	± 0.11	10%	1.98	± 0.05	2%	1.97	± 0.06	3%	1.98	± 0.07	3%
Vertical displacement (cm)	#1.92	± 0.24	13%	1.63	± 0.44	7%	1.49	± 0.41	11%	1.35	± 0.33	9%
Contact time (s)	*0.26	± 0.02	14%	*0.25	± 0.01	5%	0.24	± 0.01	4%	0.22	± 0.01	5%
Eccentric time (s)	#0.14	± 0.01	8%	0.13	± 0.00	4%	0.12	± 0.01	5%	0.12	± 0.01	5%
Concentric time (s)	*0.14	± 0.01	6%	0.13	± 0.01	4%	0.13	± 0.01	6%	0.12	± 0.01	5%
Aerial time (s)	0.27	± 0.05	16%	0.26	± 0.01	6%	0.27	± 0.01	5%	0.28	± 0.01	4%
Speed (m/s)	2.65	± 0.08	3%	2.66	± 0.05	2%	2.61	± 0.10	4%	2.65	± 0.06	2%

* significant different from 30% BM threshold $p < 0.05$

significant different from 20 and 30% BM threshold $p < 0.05$

5.5 Discussion

As the force of the steps of the pre-PHV athletes in this study did not return to zero at the completion of a step cycle, such findings necessitate the use of a step detection threshold that enables all steps to be detected whilst having minimal effect on the kinematic and kinetic outputs. To these ends, step detection thresholds of 10, 15, 20, and 30% BM were compared to determine if these thresholds affected the variables of interest. Five kinematic variables and two kinetic variables were significantly influenced by the magnitude of the step detection threshold. Most of these differences were between the 10 and 30% BM thresholds of detection. It seemed that the measurement of kinematic variables was more affected by the varying thresholds as compared to the kinetic variables, especially those kinematic variables incorporating time during the stance phase in their calculation. Intuitively this is to be expected, as the larger the threshold/cut-off the greater the loss of data in the force-time signal, which has been reported previously by other researchers (Leitch et al., 2011).

To the best of the authors' knowledge, this is the first investigation comparing different step detection thresholds whilst utilising a NMT and therefore comparisons to other studies (Butler et al., 2006; Cavanagh & Lafortune, 1980; Chang et al., 2000; Karamanidis & Arampatzis, 2005; Leitch et al., 2011; Morio et al., 2009; Riley et al., 2008; Riley et al., 2007; Weyand et al., 2010) is problematic. Our participants' average body mass was 34.8 (± 5.20 kg), therefore the mean step detection thresholds were 34.6, 51.9, 69.3, and 97.1 N for 10, 15, 20 and 30% body mass respectively. Therefore, all our threshold values were within the range of total values of 10-150 N reported by other researchers (Butler et al., 2006; Cavanagh & Lafortune, 1980; Chang et al., 2000; Karamanidis & Arampatzis, 2005; Leitch et al., 2011; Morio et al., 2009; Riley et al., 2008; Riley et al., 2007; Weyand et al., 2010) whilst analysing participants running over in-ground force plates. Relative thresholds of ~10 - 20% body mass (Riley et al., 2008), or 1% of maximal vertical force values (~35 N) (Williams & Cavanagh, 1987) were also used in running (Riley et al., 2008; Williams & Cavanagh, 1987).

An analytical goal of the CV being 10% or below has been chosen arbitrarily by some scientists, but the merits of this value as a measure of reliability are the source of conjecture (Atkinson & Nevill, 1998). Nonetheless CVs for most of the variables averaged over all thresholds were equal or less than 10%, the exceptions being power, eccentric power, vertical and leg stiffness. This high variability with power measures is similar to other research findings (Tong, Bell, Ball, & Winter, 2001) and attributed to the greater sensitivity of power as the product of force and velocity. When all measurement of variables within one threshold were averaged and compared between thresholds, the 15 and 30% BM step detection thresholds were found to have the lowest variability (6.10 and 5.90% respectively).

In summary, five kinematic (step length, vertical displacement, contact time, eccentric, and concentric time) and two kinetic (vertical and leg stiffness) variables were significantly different between the 10 versus 20 and/or 30% BM step detection thresholds in the pre-PHV population sprinting 30 metres on a NMT. Fifteen and 30% BM thresholds were found the most stable across all variables of interest. The 15% BM threshold seemed to be the most appropriate step detection threshold, as this threshold seemed to account for signal variability appropriately without compromising reliability and seemed to be the lowest threshold that should be used to reflect the “real” values of the measurement of the variables of interest.

Chapter 6

Kinematic and kinetic variables of maximum running speed in youth across maturation

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Kinematic and kinetic variables of maximum running speed in youth across maturation. *Journal of Sport Sciences*, - paper under review

6.1 Prelude

In order to improve sprint running performance of athletes, coaches need to understand which determinants of sprinting are important. Previously, the reliability of variables associated with sprint running performance was quantified and a step detection threshold of 15% of the individual's body mass was found the most appropriate for future analysis. As children grow and mature, there is no doubt that changes in height and weight associated with growth and maturation will influence sprint running performance. In order to gain a deeper appreciation of sprint running in the long-term athlete development process, the influence of both, growth (and associated changes in height and weight) and maturation on the variables of interest needs to be explored. Therefore, the purpose of this study was to investigate the influence of various kinematic and kinetic variables associated with maximum sprint velocity in male youth participants of different maturity status.

6.2 Introduction

As running velocity is a product of stride length and stride frequency (Bosco & Vittori, 1986; Mero, Komi, & Gregor, 1992), a great deal of literature has discussed the influence of these variables (Bosco & Vittori, 1986; Delecluse, Ponnet, & Diels, 1998; J. P. Hunter, Marshall, & McNair, 2004; Hunter, Marshall, & McNair, 2005; Kyrolainen, Belli, & Komi, 2001; Luhtanen & Komi, 1978; Mero & Komi, 1986; Mero et al., 1992; Nummela, Keranen, & Mikkelsson, 2007; Sinning & Forsyth, 1970; Weyand, Sternlight, Bellizzi, & Wright, 2000) and additional kinetic and kinematic factors (i.e. force, contact time, flight time, etc.) (Bosco & Vittori, 1986; Brughelli, Cronin, & Chaouachi, 2011; Cavagna, Komarek, & Mazzoleni, 1971; Luhtanen & Komi, 1978; Mero et al., 1992; Moravec et al., 1988; Nilsson & Thorstensson, 1989; Nummela et al., 2007) on sprint velocity in adult populations. Both stride frequency and length increase with increasing running velocity (Brughelli et al., 2011; Högberg, 1952; Luhtanen & Komi, 1978; Mero & Komi, 1986; Weyand et al., 2000), some researchers believing that stride frequency (Bosco & Vittori, 1986; Kuitunen, Komi, & Kyröläinen, 2002; Mero, Luhtanen, Viitasalo, & Komi, 1981; Sinning & Forsyth, 1970) to be the most important determinant of maximum velocity, whereas other researchers reported stride length (Brughelli et al., 2011; Delecluse et al., 1998) as the more important variable. Additional kinematic variables such as contact time and flight time have also been investigated at different running velocities (Bosco & Vittori, 1986; Brughelli et al., 2011; Kuitunen et al., 2002; Nilsson & Thorstensson, 1989). The main finding being that flight time and contact time (Nilsson & Thorstensson, 1989) decreased with increasing velocity up to maximum velocity (Bosco & Vittori, 1986; Brughelli et al., 2011; Kuitunen et al., 2002) in adult populations. There is a paucity of research that has investigated sprint kinematics in children. Schepens et al. (1998) investigated running mechanics in 51 healthy children, aged 2-16 years. They grouped the participants into two year age bands and found that maximum velocity increased with age, but the step frequency at maximum velocity remained constant at about 4 Hz independent of age (Schepens et al., 1998).

Kinetic variables, such as horizontal and vertical ground reaction impulse (Hay, 1994) and associated forces (Nummela et al., 2007), have also been investigated at different velocities (Brughelli et al., 2011; Kuitunen et al., 2002; Kyrolainen et al., 2001; Nilsson & Thorstensson, 1989; Nummela et al., 2007) in an adult population only. Peak and average vertical forces increased proportional to velocity (Kyrolainen et al., 2001; Nilsson & Thorstensson, 1989) up to 60% of maximum velocity and remained relatively constant up to maximum velocity (Brughelli et al., 2011). Furthermore, relative vertical force was not related to maximum running velocity ($r = 0.13$) (Brughelli et al., 2011). In another investigation, peak vertical forces were stable and did not differ significantly from 70-100% of maximal velocity (Kuitunen et al., 2002). However, horizontal forces have been shown to significantly increase with increasing speed (Brughelli et al., 2011; Kuitunen et al., 2002; Kyrolainen et al., 2001; Nummela et al., 2007) and furthermore peak horizontal forces increased in both braking/eccentric and propulsion/conecntric phases (Kuitunen et al., 2002; Nilsson & Thorstensson, 1989). In addition, Brughelli et al. (2011) reported a significant correlation (r = 0.47) between relative horizontal force and maximum running velocity. Therefore, it seems evident from this research that horizontal force production plays a role in producing maximum sprint velocity in adults.

The research cited so far appeared mostly in adult populations and there is limited knowledge about how the kinematic and kinetic variables discussed thus far influence running velocity in youth. Due to the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) at around peak height velocity (PHV), it could be hypothesised that improvements in strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990) and consequently in power output (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero et al., 1990) may affect force production. Hence, it may be that the kinetics and kinematics of running may differ in participants of contrasting maturity status and therefore affect subsequent development and trainability of these athletes. However, to the knowledge of these authors, there is no scientific evidence how age and maturation influences the kinetics and kinematics of sprint running performance. The purpose of this study therefore is to determine the kinematics and kinetics associated with maximum sprint velocity in male youth participants of different maturity status.

6.3 Methods

6.3.1 Participants

Seventy-four developing athletes between 8 and 16 years of age volunteered to participate in this study. All participants were physically active, trained a minimum of two times per week in their sport and represented their club and/or school on a regional and/or national level. The participants' characteristics can be observed in table 6.1.

Table 6.1. Characteristics (mean ± SD) of participants in all maturity groups

	Age (years)	Maturation offset (years from PHV)	Height (cm)	Leg length (cm)	Body mass (kg)
Pre-PHV (N=19)	10.6 ± 1.63	-2.78 ± 0.90	*142 ± 6.68	*66.1 ± 4.64	*35.0 ± 4.94
Mid-PHV (N=22)	14.9 ± 0.32	0.50 ± 0.49	*166 ± 6.17	*80.4 ± 4.09	*55.0 ± 7.26
Post-PHV (N=33)	15.1 ± 0.33	1.71 ± 0.51	*178 ± 8.88	*85.7 ± 6.27	*73.5 ± 13.5

*significantly different from all other maturity groups

All participants and their legal guardians were informed of the risks and benefits of participation and were provided written informed consent and assent to participate in this study. Procedures were approved by the institutional Ethics Committee of AUT University.

6.3.2 Equipment

Sprint performance was assessed using a non-motorised force treadmill (Woodway, Weil am Rhein, Germany). The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a horizontal load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), which measured horizontal force. The height of the load cell was adjusted accordingly to the subject's height, so that the tether was horizontal during testing. Vertical force was measured by four individual vertical load cells that were mounted under the running surface. The entire system was calibrated before each session using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), utilising the Pacer Performance software (Fitness Technology, Joondalup, WA, Australia), but analysed with a custom made designed Matlab (National Instruments, Austin, TX) program.

6.3.3 Testing procedures

Anthropometric measurements were taken before familiarisation on the treadmill. The height (cm), sitting height (cm) and weight (kg) was measured. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al. (2002): Maturity Offset = -9.236 + (0.0002708 * Leg Length * Sitting Height) + (-0.001663 * Age * Leg Length) + (0.007216 * Age* Sitting Height) + (0.02292 * Weight by Height Ratio). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. Generally, athletes can be categorised into 3 groups as followed: pre-PHV velocity (-3 years to -1 years from PHV), around PHV (-1 to +1 years from PHV) and post-PHV (+1 to +3 years from PHV) (Rumpf, et al. 2012). The standard error of estimate for PHV is 0.49 years for boys (Mirwald et al., 2002).

Participants then received a familiarisation session on the non-motorised treadmill, which consisted of standing, walking and running at a self-chosen speed. This familiarisation was also used as a warm-up phase if the participants felt safe and were able to perform the running without using their hands holding on to the frame of the treadmill. If the participants were unable to run freely, the data collection was postponed. A last series of warm-up sprints on the treadmill i.e. 3 x 5 seconds proceeded the initial familiarisation/warm-up period. Three sprints from a standing split start position over a distance of 30 metres were performed. The participants were allowed to recover completely after each trial (~ 4 minutes).

6.3.4 Data analysis

Data was collected at a sampling rate of 200 Hz utilising the Pacer Performance software (Fitness Technology, Joondalup, WA, Australia) and analysed with a custom designed Matlab (National Instruments, Austin, TX) program. Each channel of data was filtered using a low pass digital Butterworth zero-lag filter and optimised cut of frequencies based on the residual analysis (Winter, 2005). Vertical, horizontal forces and running velocities were measured directly, via four individual vertical load cells that were mounted underneath the running surface, a horizontal load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), and two optical speed photomicrosensors in conjunction with a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia) respectively. Step length, step frequency, contact time, aerial time and power were calculated. Variables were defined as follows:

Step length: Difference in distance from start to end of step detection threshold

Step frequency: 1/contact time + aerial time of a step

Contact time: Difference in time of start and end of step detection threshold

Aerial Time: Time outside the step detection threshold

Power: Peak horizontal forces * velocity

Steps were identified when the force was greater (foot touchdown) or smaller (toe-off) than 15% of the subjects' body mass. The data was then separated into right and left steps using the individual force plates' force signal from the Woodway. The fastest four consecutive steps were chosen and averaged for further analysis.

6.3.5 Statistical analysis

Means and standard deviation for all dependent variables of interest were used as measures of centrality and spread of data. Percent changes were calculated from pre- to mid- and mid- to post-PHV group, by dividing the variable of interest of the older group by 1% of the same variable from the younger maturity group minus 100. A one way analysis of variance (ANOVA) with Bonferoni post hoc comparisons, were used to detect statistical difference in the variables of interest between maturity status. An analysis of covariance (ANCOVA) with Bonferoni post hoc comparisons was used to detect differences by removing the variance of certain predictor variables (e.g. maturation and age) which were thought influential on the maximal velocity. To identify which kinematic and kinetic factors were important in achieving maximum velocity, multiple linear stepwise regression analyses were conducted. From this analysis, the best multiple-predictor model for maximum velocity was derived. Regression diagnostics were used to determine whether any outliers were present, whether the data were normally distributed and issues with multicollinearity were identified and adjusted for. The forward stepwise regression began with no variables in the equation and thereafter entered the most significant predictor at the first step and continued to add or delete variables until none significantly improved the fit. Minimum tolerance for entry into the model and alpha-to-enter/remove were set at 0.05 and 0.10 respectively. An alpha level of 0.05 was used for all statistical tests.

6.4 Results

As can be observed from table 6.1, height, leg length and body mass increased significantly with each maturity group. Averaged values for the variables of interest and their percent change across the three maturity groups are reported in table 6.2.

Table 6.2. Maximum velocity kinematics and kinetics (mean ± SD) for pre-, mid- and post-PHV groups

	Pre-PHV		Mid-PHV		Post-PHV		%change pre-mid PHV	%change mid-post PHV	%change pre-post PHV
Speed (m/s)	*2.64	± 0.34	*3.69	± 0.30	*4.04	± 0.30	39.5	9.64	53.0
Step length (m)	0.79	± 0.12	#1.09	± 0.14	#1.12	± 0.10	38.6	3.22	41.8
Step frequency (#/s)	1.93	± 0.21	#2.08	± 0.19	#2.05	± 0.16	7.81	-1.24	6.22
Contact time (s)	0.25	± 0.04	0.23	± 0.03	#0.22	± 0.02	-8.07	-4.74	-12.0
Aerial Time (s)	0.28	± 0.08	0.25	± 0.03	0.27	± 0.03	-10.4	6.28	-3.57
VForce (N)	*774	± 130	*1239	± 193	*1749	± 335	60.0	41.2	126
VForce/BM (N/kg)	22.1	± 2.44	22.5	± 2.22	*23.9	± 1.80	1.35	6.22	7.66
HForce (N)	206	± 34.1	#263	± 44.9	#267	± 33.4	27.8	1.50	29.6
Power (W)	546	± 131	#963	± 194	#1074	± 167	76.3	11.5	96.7

Key: # = amount; V = vertical; BM = body mass; H = horizontal
*Significantly different from all other maturity groups
#Significantly different from pre-PHV group

In terms of the kinematic variables, it can be observed that speed increased significantly ($p < 0.05$) across each maturity status (%change of ~40 and ~10% for pre- to mid- and mid- to post-PHV group respectively). Step length was significant lower in the pre-PHV participants than in either the mid- or post-PHV participants; however, the difference (~3%) between mid-to post-PHV was non-significant. Step frequency was significantly lower in the pre- compared to mid- (~8%) and post-PHV (~6%) participants. A significant lower mean of ~5% in more mature participants (mid- vs. post-PHV participants) was reported for contact time, while there was no change in aerial time with maturation. When the percent change for all kinematic variables was averaged between maturity groups, greater changes were found in the pre- to mid-PHV comparison (20.9%) as compared to the mid- to post-PHV comparison (5.00%).

With regards to the kinetic variables, it can be observed from table 6.1 that vertical force was the only kinetic variable that increased significantly across all three maturity groups (~40 - 60%). However, relative vertical forces (i.e. force/body mass) showed significant higher values in post-PHV participants compared to pre- and mid-PHV participants. Horizontal force and power in the mid- and post-PHV groups (52.1%) were significantly higher only to the pre-PHV group but not to each other (~ average 6.5%).

The effect of certain covariates (age and maturation) on maximum velocity across groups was investigated. When maturation was entered as a covariate, there was no significant velocity effect across the three maturity groups. However, all groups were significantly different from each other when age was chosen as the covariate.

With regards to the regression analysis (see table 6.3), the two best predictors of maximum velocity were power and horizontal force for pre- and post-PHV participants, explaining 97-99% of the shared variance. Vertical force, step length and contact time were the best predictors of maximum velocity for the mid-PHV, however, the three-predictor-model only explained 69.6% of sprint performance.

Table 6.3. Predictor variables for maximal velocity in each group

Group	Predictor variables	R-square	R-square change
Pre-PHV	Power	0.59	0.59
	Horizontal force	0.98	0.39
Mid-PHV	Vertical force	0.33	0.33
	Step length	0.59	0.25
	Contact time	0.70	0.11
Post-PHV	Power	0.35	0.35
	Horizontal force	0.99	0.65
Groups combined	Power	0.76	0.76
	Horizontal Force	0.97	0.20
	Step length	0.97	0.00
	Contact time	0.98	0.01

6.5 Discussion

Our findings support the limited body of evidence which reported increases in maximal velocity with maturation (Ford et al., 2010; Philippaerts et al., 2006). The greatest increases in maximum velocity appeared from pre- to mid-PHV status (39.5%) as compared to mid- to post-PHV participants (9.64%). The ensuing discussion addresses those kinematic and kinetic variables associated with these velocity increases. However, the reader needs to be cognisant that there is very little literature which has investigated the kinematics and kinetics of sprinting across maturation and therefore comparisons to the existing literature in many cases is impossible and/or problematic.

The maximal velocity obtained from the participants in this study increased significantly across maturation. As velocity increased with maturation, it was not surprising that both step length and step frequency increased significantly from pre- to mid- and post-PHV participants. Generally, step length is attributed to height and therefore leg length, both of which increased significantly across all maturity groups. Both measurements change during the adolescent growth spurt and developmental athletes reach nearly 95% of their adult height when achieving PHV (Malina, Bouchard, & Bar-Or, 2004). This most likely explains why step length was significantly different from pre-to mid-PHV (38.6%) but not from mid- to post-PHV (3.22%) participants. Given that velocity is the product of step length and step frequency (Hay, 1994; Hunter et al., 2004), it would seem that other factors than those two influenced maximal velocity from mid- to post-PHV participants.

As velocity is the product of step length and step frequency (Hay, 1994; Hunter et al., 2004), step frequency is an important determinant of sprint velocity and was found to differ significantly between pre-to mid- and post-PHV participants but not between mid- to post-PHV. Controversially, Schepens et al. (1998) found that step frequency at maximum velocity remained constant with age. Despite the results, comparisons between this study and ours are difficult as these researchers used a force plate during data collection, did not provide raw values and did not group the healthy children into maturity categories. Nonetheless, it seems that the increase in step length (41.8%) from pre- to post-PHV participants is greater compared to that of step frequency (6.22%) and is seemingly a more important determinant of maximum velocity. Intuitively, the discrepancy between increases in step length and frequency makes sense because as athletes grow, limb lengths and step lengths would increase accordingly.

The increase in velocity across maturation in our study was also accompanied with shorter ground contact times (0.25 to 0.22 s), these are findings similar to findings with adults (Clark et al., 2009; Mero & Komi, 1985). However, only post-PHV participants were significantly different from pre-PHV participants. The ability to produce a great deal of force in a short amount of time is an important determinant of speed (Hay, 1994; Weyand et al., 2000). It seems that in more mature runners the ability for fast force production is better developed and may explain some of the increases in velocity with maturation. It may be that increases in musculotendinous stiffness with maturation might account partly for the shorter ground contact times. That is, it has been reported that the musculotendinous tissue of younger athletes is more compliant and research using sub-maximal and maximal hopping found that 12 and 15 year olds applied significantly greater force within the same ground contact time as nine-year olds (Lloyd, Oliver, Hughes, & Williams, 2012). Furthermore, it was reported that absolute stiffness increased significantly from 9 to 12 and 15-year olds and the latter group produced significant greater absolute leg stiffness than the two younger groups (Lloyd et al., 2012). However, further research is needed to elaborate the role of stiffness on contact time and change of velocity in youth of different maturity status whilst sprinting.

Aerial time did not differ significantly between maturity groups. With regards to the higher maximum velocities achieved by more mature athletes, it would seem that increasing speed was not influenced significantly by the aerial or flight phase, these are similar to over-ground sprinting results in adults (Coh, Milanovic, &Kampmiller, 2001; Mero & Komi, 1985). As aerial time is relatively unchanged throughout maturation, it seems that the repositioning of the limbs during the flight time remains relatively constant and that the increase in SF is most likely attributable to the slight decrease in contact time with maturation. This is similar to research in adults

(Weyand et al., 2000) and implicates the importance of force application during the ground contact period across maturation.

The vertical ground reaction forces (774 to 1749 N) were significantly different across all maturity groups, with average changes of ~40 to 60% being observed (see table 6.2). However, there is no doubt that the differences in vertical force across maturity groups were affected by body mass changes with maturation thus the introduction of the relative vertical force measures (i.e. vertical force/body mass). Post-PHV relative vertical forces were found to be significantly greater than in the other two maturity groups. That is, the post-PHV were producing more force per kg of body mass, suggesting that qualitative changes in muscle structure and function were occurring during this stage of maturation i.e. greater lean muscle mass, fibers becoming more pennate, increased stiffness, etc.

As can be observed from table 6.2, horizontal force production was much less than vertical force and did not change a great deal across maturation (in full 30%) and the only significant differences were from pre-PHV to both mid- and post-PHV groups. Studies with adults have shown the importance of horizontal force production in increasing velocity (Brughelli et al., 2011; Weyand et al., 2000); however, this is the first study to discuss the effects of horizontal force production in determining maximum velocity across maturation. Furthermore, the inclusion of horizontal force in the predictor models of the pre- (39%) and post-PHV groups (65%) added substantially to explaining maximal velocity in the regression analysis. It seems horizontal force plays a major role in the development of velocity across maturation; however, the absence of horizontal force as a predictor variable in the mid-PHV group is perplexing and might indicate some degree of adolescent awkwardness. That is, it is a period of accelerated growth where the height changes are outstripping changes in weight (Beunen & Malina, 1988) which may affect force and technique capability temporarily. This is probably because of the greater growth rates of the limbs in comparison to the trunk. In the months before PHV, the limbs have their PHV and this might causes the temporary disruption to co-ordination and speed. In the mid-PHV group, the subjects could be in a period where their limbs are growing rapidly or a period where this growth has started to stabilise. So some individuals are experiencing awkwardness and those beginning to overcome for this (Beunen & Malina, 1988). This may mean the factors that determine speed in this phase of maturation to be more variable as this is a more “unstable” group.

The power output, calculated as the product of peak horizontal forces and velocity, of the mid and post-PHV participants (~900 - 1100 W) of this study was found to differ significantly to pre-PHV participants (~ 500 W) but not to each other. Power output of participants aged 12 to 16 year olds whilst sprinting on a torque or non-motorised treadmill have been reported previously (Bloxham, Welsman, & Armstrong, 2005; Falk et al., 1996; Ratel, Williams, Oliver, & Armstrong, 2004) and increased with age (Bloxham et al., 2005; Falk et al., 1996; Ratel et al., 2004) from

321 W in 12 year olds (Bloxham et al., 2005) to 807 W in 16 year olds (Falk et al., 1996). It should be noted that comparisons between studies are problematic as different equipment was used, different calculations (i.e. peak versus mean power) and durations of calculation ranged from 2.5 to 30 seconds (Bloxham et al., 2005; Falk et al., 1996; Ratel et al., 2004). In the present study peak power values were obtained from the fastest four steps. Power was identified as the best predictor of maximal velocity in pre- (59%), post-PHV (35%) and all groups combined (76%) in the regression analysis which showed the importance of power production whilst sprinting. Therefore, power and horizontal force combined were shown as major determinants of maximal velocity throughout maturation and explained 97-99% of the shared variance.

As mentioned earlier, power was calculated as horizontal force multiplied by velocity; it would seem that horizontal force substantially influences maximal velocity. It may be argued that this may be a result of using a non-motorised treadmill, the kinematics and kinetics of which may be different to over-ground running. However, many studies have cited the importance of horizontal force to increasing maximum velocity in adults (Brughelli et al., 2011; Kuitunen et al., 2002; Kyrolainen et al., 2001; Nummela et al., 2007) and the results of this study certainly support such findings.

Finally, changes in maturation and not age as proposed by Balyi (2005) seemed to determine maximum velocity development. This may be attributed to the hormonal changes around PHV and subsequent changes in lean muscle mass.

6.6 Practical applications

Maximum running velocity increased across all maturity groups with the greatest average percent change in kinetics and kinematics, observed from pre- to mid-PHV (37.8%) compared to mid- to post-PHV groups (11.6%). Given the magnitude of the changes in the pre-to mid-PHV groups it would seem that a great deal of time should be dedicated to sprint training during these years. It is suggested that training is principally kinematic/technique and co-ordination focused given the biological maturation of this group, the outcome efficient running mechanics. It would also seem that this group would benefit from techniques cues and/or exercise prescription that optimises their horizontal force capability.

There is no doubt that technique training needs to continue through all phases of maturation and certainly when the rate of PHV changes the most (i.e. around mid-PHV), to combat adolescent awkwardness. The results of this study also suggest that the ability to produce vertical force, and to optimise step length and decrease contact time, seems to be critical predictors of maximal velocity during mid-PHV.

Technique and strength training targeting these variables may benefit the athletes of this maturity status.

The training of post-PHV participants should focus on exercises targeting kinematic (step length and frequency) and kinetic (horizontal force and power) variables. Additionally, athletes around post-PHV status should include training that reduces contact time during sprinting and increase lean muscle mass.

Finally, maturation, not age, seems to be a key factor in the development of maximal velocity. Implicit in this, is the need to assess the maturity status of athletes so programming can be matched to the maturational needs of the developmental athlete.

Chapter 7

Vertical and leg stiffness and stretch-shortening-cycle changes across maturation during maximal sprint running

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Vertical and leg stiffness and stretch-shortening-cycle change across maturation during maximal sprint running. *Human Movement Science,* - paper under 3rd review.

7.1 Prelude

Several variables and their influence on maximal running velocity in youth across maturation were investigated in the previous chapter. Step length, step frequency, vertical and horizontal force, and horizontal power were deemed as important determinants of maximum velocity and changed significantly from pre- to mid-PHV maturity status. While the influence of maturation on those variables are clarified, additional variables and their combination such as the vertical force associated with the displacement of the centre of mass (vertical stiffness) and the power associated with different phases of contact time (eccentric - power absorption; concentric - power production) are thought to influence sprint running performance as well. While stiffness and the power absorption-production during the stretch-shortening cycle (SSC) and their influence on sprint running performance have been reported in adults, no studies have investigated the importance of these measures across maturation. Implicit in growth and maturation, is the change in the physiology and structure of bones, ligaments, tendons and muscles of athletes. However, how these changes influence SSC ability whilst running/sprinting is unknown. Therefore, the purpose of this study was to investigate leg and vertical stiffness and, power absorption and production during sprinting in athletes of different maturity status.

7.2 Introduction

Vertical and leg stiffness (Cavagna, Heglund, & Willems, 2005; Farley & Gonzalez, 1996) are variables that seem to have a role in sprint running performance (Brughelli & Cronin, 2008). Vertical and leg stiffness reflect the maximum vertical force and the displacement of the center of mass during running/sprinting and depending on its calculation express dimensionless variables (McMahon & Cheng, 1990) of leg elasticity (Mero & Komi, 1986). Leg stiffness is calculated by the change in length of the stance leg, taking the landing angle into account, while vertical stiffness is calculated by using the vertical displacement of the center of mass. Both variables have been investigated in adults (Arampatzis, Bruggemann, & Metzler, 1999; Cavagna, Franzetti, Heglund, & Willems, 1988; Cavagna et al., 2005; He, Kram, & McMahon, 1991; McMahon & Cheng, 1990; McMahon, Valiant, & Frederick, 1987; Morin, Dalleau, Kyrolainen, Jeannin, & Belli, 2005; Morin, Jeannin, Chevallier, &

Belli, 2006) and only limited information is available in youth (Chelly & Denis, 2001; Heise & Bachman, 1999; Schepens, Willems, & Cavagna, 1998).

Heise and Bachman (1999) presenting values of 25-55 kN/m for vertical stiffness and a proportionality with body mass, i.e. increases in stiffness due to an increase in body mass and therefore vertical ground reaction force. However, with regard to the development of mass-specific vertical stiffness across age, it was reported by Schepens et al. (1998) that a decrease in stiffness appears due to an increase in body mass with a constant stiffness. Values of leg stiffness in youth whilst running were reported between 3-14 kN/m (Heise & Bachman, 1999). Researchers have also investigated the correlation of vertical stiffness with running velocity in adolescence and adult populations, with many of the results conflicting. Hopping on a force plate was correlated (r = 0.68) with maximum velocity at 40 metres in adolescents (Chelly & Denis, 2001), with mean velocity over 30–100 metre distance (r = 0.66) (Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002) and the entire 100 m distance (r = 0.54) in adults (Morin et al., 2006). Vertical stiffness during hopping was not correlated with the acceleration phase or sprint running performance (Bret et al., 2002; Chelly & Denis, 2001). Morin et al. (2006) also found leg stiffness was not significantly correlated with any distance during a 100-m sprint, however, vertical stiffness was correlated with mean forward velocity during contact and mean forward velocity over the entire 100 metre distance (Morin et al., 2006).

Interestingly, fatigue had significant effects on vertical but not on leg stiffness (Morin et al., 2006).

The application of force into the ground (ground reaction force) is an important determinant of sprint velocity. These ground reaction forces can be divided into braking and propulsion forces (Mero & Komi, 1986). As a result, every step consists of an eccentric followed by a concentric muscle phase (Dalleau, Belli, Bourdin, & Lacour, 1998; Komi & Gollhofer, 1997; Wilson & Flanagan, 2008). During the eccentric phase mechanical energy is stored in the elastic elements of the support leg and released during the concentric phase (Dalleau et al., 1998; Morin et al., 2006). This eccentric-concentric coupling has been termed a stretch-shortening cycle (SSC) (Blickhan, 1989; Komi, 1984; McMahon & Cheng, 1990; McMahon et al., 1987; Morin et al., 2006; Norman & Komi, 1979; Novacheck, 1998) and has been found to potentiate force and power output and therefore performance (Komi, 1984) and reduce energy expenditure (Cavagna, Dusman, & Margaria, 1968; Cavagna, Saibene, & Margaria, 1964; Komi, 1984) during walking and running.

The benefits of the SSC are undoubted in athletic performance, however, in order to utilise the SSC optimally, several conditions need to be considered (Komi & Gollhofer, 1997): muscles need to be pre-activated before ground contact (Komi, 1984); the eccentric phase needs to be rapid (Komi, 1984; Komi & Gollhofer, 1997); the time (coupling time) between the eccentric and concentric transition needs to be minimized (Komi, 2000); and, the duration of the entire SSC seems to be crucial as well (Schmidbleicher, 1992; van Ingen Schenau, Bobbert, & de Haan, 1997).

Increasing speed during running will decrease the contact time of a step and therefore the duration of the eccentric and concentric phases (Bosco & Rusko, 1983; Nummela, Keranen, & Mikkelsson, 2007; Coh, Milanovic, & Kampmiller, 2001; Kuitunen, Komi, & Kyröläinen, 2002; Mero & Komi, 1985; Mero & Peltola, 1989; Nummela et al., 2007; Weyand, Sternlight, Bellizzi, & Wright, 2000). Consequently the time for the production and utilisation of elastic energy derived from the aforementioned contact times is affected. As it is evident, the SSC is a very important component of athlete’s running/sprinting performance and the connection between SSC and sprinting has been studied in adult populations (Hennessy & Kilty, 2001; Nesser, 1996).

Due to the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around peak height velocity (PHV – non-invasive measure of maturation) and subsequent anthropometric changes (height, weight, muscle mass, etc.), large improvements in strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990), and consequently power output (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero et al., 1990) are known to occur, which affect force production and sprint capability. Consequently, kinetic variables such as SSC characteristics (power absorption and production) and vertical and leg stiffness could be different in athletes of different maturity status, even when normalized with body mass and leg length. However, whether this is the case is unknown. Given this and the preceding information regarding the lack of research in this area with youth, the purpose of this study was to investigate whether vertical and leg stiffness, and stretch-shortening cycle (SSC) ability differed in developing athletes of various maturity status during maximal sprint running.

7.3 Methods

Seventy-four male athletes between 8 and 16 years of age volunteered to participate in this study. All participants were physically active, trained a minimum of two times per week in their sport and represented their club and/or school on a regional and/or national level. The participant's characteristics can be observed in table 7.1.

Table 7.1. Characteristics (mean ± SD) of participants across maturity groups

	Age (years)	Maturation offset (years from PHV)	Height (cm)	Leg length (cm)	Body mass (kg)
Pre-PHV (N=19)	10.6 ± 1.63	-2.78 ± 0.90	*141.6 ± 6.68	*66.1 ± 4.64	*35.0 ± 4.94
Mid-PHV (N=21)	14.9 ± 0.32	0.50 ± 0.49	*166.1 ± 6.17	*80.4 ± 4.09	*55.0 ± 7.26
Post-PHV (N=34)	15.1 ± 0.33	1.71 ± 0.51	*178.2 ± 8.74	*85.7 ± 6.27	*73.1 ± 8.74

* Significantly different from all other maturity groups ($p < 0.05$)

All participants and their legal guardians were informed of risks and benefits of participation in the research and both, legal guardians and participants, provided written informed consent and assent to participate in this study. Procedures were approved by the institutional Ethics Committee of AUT University.

7.3.1 Design

This study examined the vertical and leg stiffness and stretch-shortening cycle in pre-, mid- and post-PHV youth during maximal sprint running. Seventy four participants sprinted over 30 metres on a non-motorised treadmill. Kinetic and kinematic variables of interest were obtained from the fastest four consecutive steps. Data and statistical analysis was performed with regards to the three different maturity groups, which are defined below.

7.3.2 Methodology

7.3.2.1 Data collection

Sprint performance was assessed using a non-motorised force treadmill (Woodway, Weil am Rhein, Germany). The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a horizontal load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), which measured horizontal force. The height of the load cell was adjusted according to the subject's height, so that the tether was horizontal during testing. Vertical force was measured by four individual vertical load cells that were mounted under the running surface. The entire system was calibrated before each session using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Each channel of data was filtered using a low pass digital Butterworth zero-lag filter and optimised cut off frequencies were used based on the residual analysis (Winter, 2005). Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), but analysed with a custom made designed Matlab (MathWorks, Inc., Natick. MA, USA) program.

Anthropometric measurements were taken. The height (cm), sitting height (cm) and weight (kg) were measured. To calculate the maturation of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al.

(2002): Maturity Offset = -9.236 + (0.0002708 × leg length × sitting height) + (-0.001663 × age × leg length) + (0.007216 × age × sitting height) + (0.02292 × weight by height ratio). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturation using anthropometric variables. Generally, athletes were then categorised as follows: pre-PHV velocity (-3 years to -1 years from PHV), around PHV (-1 to +1 years from PHV) and post-PHV (+1 to +3 years from PHV) (Rumpf, Cronin, Oliver, & Hughes, 2012).

Participants then received a familiarisation session on the non-motorised treadmill, which consisted of standing, walking and running at a self-chosen speed. This familiarisation was also used as a warm-up phase if the participants felt safe and were able to perform the running without using their hands holding on to the frame of the treadmill. If the participants were unable to run freely, the data collection was postponed. A last series of warm-up sprints on the treadmill i.e. 3 x 5 seconds preceded the testing session. Three sprints from a standing split start position over a distance of 30 metres followed. The participants were allowed to recover completely after each trial (~ 4 minutes).

7.3.2.2 Data analysis

While vertical and horizontal force and speed were directly measured from the non-motorised treadmill, contact time, eccentric and concentric time, eccentric and concentric power, vertical displacement, and vertical and leg stiffness were calculated. Variables were defined as followed:

Contact time was defined as the time when the subjects foot was in contact with the treadmill. *Eccentric time* was defined as the time from the beginning of the step until zero vertical velocity. The vertical velocity was calculated from the second derivation of the maximum vertical force. *Concentric time* was defined as the time from zero vertical velocity to the end of the step. *Eccentric* and *concentric power* was defined as the average horizontal force multiplied with velocity during the respective phases. *Vertical stiffness* was calculated from the maximum ground reaction forces during contact divided by the vertical displacement of the center of mass as described by McMahon and Cheng (1990). Vertical displacement was determined by double integration of the vertical acceleration (Cavagna et al., 1988) in the eccentric phase. Vertical acceleration was obtained from the peak vertical force divided by body mass after subtracting gravitational acceleration (Cavagna et al., 1988). *Leg stiffness* was calculated as the maximum vertical force (F_{max}) divided by the peak displacement (Δ) of the initial leg length (L) (Morin et al., 2005), calculated from standing height minus sitting height:

$$k_{leg} = F_{max} \times \Delta L^{-1}$$

The peak displacement of the initial leg length was calculated as:

$$\Delta L = L - \sqrt{L^2 - \left(\frac{vt_c}{2}\right)^2} + \Delta y_c$$

where v = running velocity (in m × s^{-1}), t_c = contact time (in seconds) and Δy_c= the vertical displacement (in metres) of the center of mass when it reached its lowest point during mid-stance. Dimensionless leg and vertical stiffness were derived from further multiplying the two stiffness measures with the initial leg length and then dividing the product by the participants' body mass multiplied by gravitational acceleration of 9.81 (McMahon & Cheng, 1990) .

Steps were identified when the force was greater (foot touchdown) or smaller (toe-off) than 15% of the participants' body mass. This threshold was found to provide the most reliable results during pilot testing. Data were then separated into right and left steps using the individual force plate signals from the non-motorised treadmill. The fastest four steps were chosen and averaged for further data analysis.

7.3.3 Statistical analysis

Means and standard deviations for all dependent variables of interest were used as measures of centrality and spread of data. Percent changes were calculated from pre- to mid- and mid- to post-PHV group. A one way analysis of variance (ANOVA) with Bonferoni post hoc contrasts, was used to detect difference in the variables of interest between the three maturity groups. An analysis of covariance (ANCOVA) with Bonferoni post hoc contrast was used to detect differences by removing the variance of certain predictor variables (e.g. years off PHV, age) which were thought influential on the maximal running velocity. To identify which kinematic and kinetic factors were important in achieving maximum velocity, multiple linear stepwise regression analyses were conducted. From this analysis, the best multiple-predictor model for maximum velocity was derived. Regression diagnostics were used to determine whether any outliers were present, whether the data were normally distributed and whether there were any issues with multicollinearity. The forward stepwise regression began with no variables in the equation and thereafter entered the most significant predictor at the first step and continued to add or delete variables until none significantly improved the fit. Minimum tolerance for entry into the model and alpha-to-enter/remove were set at 0.05 and 0.10 respectively. An alpha level of 0.05 was used for all statistical tests.

7.4 Results

Anthropometric variables can be observed from table 7.1. Height, leg length and weight increased significantly with increasing maturation. Averaged values for all other variables of interest and the percent difference for the pre-, mid- and post-PHV group are reported in table 7.2.

Table 7.2. Average kinematic and kinetic variables at maximal velocity during a 30 metre sprint for all maturity groups

	Pre-PHV	Mid-PHV	Post-PHV	%change pre-mid PHV	%change mid-post PHV	%change pre-post PHV
Vertical stiffness	*40.8 ± 13.7	*54.4 ± 12.9	*65.7 ± 13.3	29.8	21.1	61.0
Leg stiffness	4.09 ± 1.15	^4.99 ± 1.15	*5.91 ± 1.25	17.4	18.4	44.5
Eccentric time (s)	0.14 ± 0.03	0.13 ± 0.02	#0.12 ± 0.01	-9.29	-9.23	-14.3
Concentric time (s)	0.14 ± 0.02	#0.12 ± 0.01	#0.11 ± 0.01	-8.57	-9.17	-21.4
Eccentric power (W)	403 ± 130	#764 ± 164	#878 ± 208	89.6	14.9	118
Concentric power (W)	*495 ± 105	*775 ± 208	*919 ± 145	56.6	18.6	85.7
Max velocity (m/s)	*2.64 ± 0.34	*3.69 ± 0.30	*4.04 ± 0.30	39.8	9.49	53.0

* Significant different from all other maturity groups
#Significant different from pre-PHV group
^ Significant different from post-PHV group

Maximum velocity increased with maturity and was significantly greater between each maturity group. Only two other variables (dimensionless vertical stiffness and concentric power) exhibited similar trends, that is, all between-group comparisons were significantly different to each other. In terms of the kinetic variables, dimensionless leg stiffness was significantly greater in post-PHV compared to mid- and pre-PHV and eccentric power was significantly greater in mid- and post-PHV participants compared to pre-PHV participants.

In terms of the kinematic variables, concentric and eccentric time decreased with increasing maturation and were significantly lower (~-14 to 21%) in post- compared to pre-PHV participants for both variables. Additionally, mid-PHV participants had significantly shorter concentric times compared to pre-PHV participants.

When maturity offset (years from PHV) was controlled for, no significant changes were present between all maturation groups in dimensionless vertical and dimensionless leg stiffness, eccentric and concentric time and eccentric and concentric power. However, when age was used as a covariate, significant differences between pre- and mid-PHV compared to post-PHV in eccentric and concentric power were found.

With regards to the best predictors of maximum velocity, it can be observed in table 7.3 that eccentric or concentric power, best predicted maximum velocity across all maturity groups.

Table 7.3. Predictor variables for maximal velocity across maturity groups

Group	Predictor variables	R-square	R-square change
Pre-PHV	Eccentric power	0.68	0.68
Mid-PHV	Concentric power	0.37	0.37
Post-PHV	Eccentric power	0.61	0.61

While eccentric power explained 61 - 68% of maximal velocity in pre- and post-PHV participants, concentric power accounted for 37% of the shared variance in mid-PHV participants.

7.5 Discussion

Vertical stiffness in this study increased significantly across maturation (61.0%). Two studies have reported vertical stiffness results for children (Heise & Bachman, 1999; Schepens et al., 1998) whilst running or sprinting. A decrease in mass-specific vertical stiffness, due to an increase in body mass of the participants with a constant stiffness before the age of 12, was reported (Schepens et al., 1998) whilst other researchers reported an increase in stiffness with age (Heise & Bachman, 1999;

Schepens et al., 1998). Values for vertical stiffness, visualized in a graph by Heise and Bachman (Heise & Bachman, 1999), were between 25-55 (Heise & Bachman, 1999) for boys and girls between the age of 5-10 years of age. Our values (27-55 for pre-PHV) were similar to the results of those researchers (Heise & Bachman, 1999). However, it needs to be noted that comparisons between studies are problematic given the different genders and methodologies. Furthermore, the same authors provided a linear regression analysis of vertical stiffness as a function of body mass revealing an increase of vertical stiffness with body mass. Researchers have reported an increase in stiffness with increasing velocity in adults (Arampatzis et al., 1999; McMahon et al., 1987; Morin et al., 2005), however the present study is the first to report the influence of maturation on dimensionless vertical stiffness increases in youth with maturation whilst sprinting.

Vertical stiffness has been shown to be greater than leg stiffness in a number of studies (Arampatzis et al., 1999; Blickhan, 1989; McMahon & Cheng, 1990; Morin et al., 2006), and a similar pattern was observed in the present study. A significant increase (44.5% from pre- to post-PHV) of leg stiffness measures with maturation was observed in our study, with leg stiffness values similar to the lower ranges of data reported by Heise and Bachman (1999). In the current study, leg stiffness was between 3-14 for boys and girls between the ages of 5-10 years, however, it needs to be noted that comparisons between studies are problematic as discussed previously. Changes in leg stiffness in youth have been found for a hopping task on a force plate

(Lloyd, Oliver, Hughes, & Williams, 2012). Lloyd et al. (2012) reported that older participants (15 years of age) produced significantly greater absolute (>60%) and relative (~14%) leg stiffness compared to their younger peers (9-12 years of age). Leg stiffness in our study also increased across maturity groups (~17-45%) during maximum sprint running.

Eccentric contact time decreased with maturation (-9.29% for pre- to mid-PHV participants and -14.3% for pre- to post-PHV participants) and was significantly less in post- compared to pre-PHV participants. Concentric time also decreased significantly with maturation from pre- to mid- (-8.57%) and post-PHV (-21.4%) participants. Generally, it seems that more mature participants (mid- and post-PHV) spend less time in the eccentric and concentric phase whilst sprinting at a higher speed (compared to pre-PHV participants).The decrease in eccentric and concentric contact times can most likely be attributed to increasing leg and vertical stiffness with maturation.

Power absorption (eccentric power) and power production (concentric power) can be used as indices of the storage and utilisation of the elastic energy of the musculotendinous system or SSC ability. Interestingly, concentric power was significantly different between all maturity groups, while eccentric power was only different between pre- to mid- and post-PHV groups. It seems from these results, that the ability to store/absorb power improves until PHV while the ability to utilise/produce power develops throughout the athletes' maturation. Even though eccentric and concentric power were the best predictors of maximal running velocity across all maturation groups, it seems that the ability for increased power production is refined with maturation given: a) significantly higher power production with similar concentric and eccentric times (mid- vs. post-PHV); b) significantly higher power production with shorter eccentric times (post- vs. pre-PHV) and concentric time (post- and mid- vs. pre-PHV); and, c) because age explained only changes in pre- and mid-PHV compared to post-PHV participants in both power measurements. It seems from our analysis that maturation plays a greater role in power storage and utilisation and consequently SSC development at maximal running velocity compared to age. The rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier et al., 1969; Kraemer, 1988; Ramos et al., 1998; Round et al., 1999) around PHV and subsequent anthropometric (height, weight, muscle mass, etc.), and physiological changes in the muscle and/or tendon structures might partly explain the differences in the SSC ability between groups. Changes in tendon compliance with age has been investigated (Kubo, Kanehisa, Kawakami, & Fukanaga, 2001) and differences in the ratio of fascicle length to thigh length showed the greater compliance for 11 compared to 15 years old (Kubo et al., 2001).

As observed in over-ground sprinting, low contact time and high power production are critical for speed development in adults (Kuitunen et al., 2002; Nilsson &

Thorstensson, 1989). While there is no research to the knowledge of these authors that has investigated SSC in youth whilst sprinting, there is limited evidence in jumping (Lloyd, Oliver, Hughes, & Williams, 2011; Lloyd et al., 2012). Lloyd et al. (2011) reported significantly greater jump height of 12 and 15 year olds with the same ground contact time compared to nine-year olds (Lloyd et al., 2012). The authors concluded that maturity-dependent changes in the structural components of the musculotendinous tissue influenced performance. It has been reported that the musculotendinous tissue of younger athletes is more compliant (Kubo et al., 2001; Lambertz, Mora, Grosset, & Perot, 2002; O'Brien, Reeves, Baltzopoulos, Jones, & Maganaris, 2010) and whilst better for storing energy during slow SSC movements, it is less effective during fast SSC movements such as ground contact in sprinting. Therefore age (Kubo et al., 2001; Lin, Brown, & Walsh, 1997) or maturation (Lambertz et al., 2002; O'Brien et al., 2010)-related changes in muscle (Lin et al., 1997), tendon (Kubo et al., 2001; O'Brien et al., 2010) or musculotendinous tissue (Lambertz et al., 2002), and consequently greater leg stiffness, seemed a reasonable explanation for an increase in the SSC ability of the youth in our study. Another possible explanation for the enhanced SSC ability of post-PHV participants is the change of the stretch reflex with age and maturation (Grosset, Mora, Lambertz, & Perot, 2007; Lin et al., 1997). It has been reported (Grosset et al., 2007) that younger children have lower musculoarticular stiffness (i.e. greater compliance) and lower muscle preactivation. As a result, stiffer tissues in older participants will enable greater reflex potentiation and subsequent SSC augmentation.

In conclusion maximum velocity increased significantly across all maturation groups, these changes were greater from pre- to mid- (39.8%) than from mid- to post-PHV participants (9.49%). The differences in maximum running velocity can be partly explained by the neuromuscular system's ability to store and produce horizontal power, which are no doubt influenced by the stiffness of the tissues involved and the subsequent effects on ground contact time. Therefore, the authors conclude, that in fact vertical stiffness and SSC ability (power absorption and production) may increase during an athletes' development. In addition, it appears that these variables influence maximal running velocity.

7.6 Conclusions

To the authors' knowledge, this is the first study to report vertical and leg stiffness, and SSC ability at maximal velocity in youth of different maturity status. Vertical and leg stiffness and especially SSC ability seemed to contribute to maximum velocity and the greatest changes appeared at time of peak height velocity. It seemed that maturation affects the ability to store and utilise energy and furthermore aid in developing maximal velocity.

Chapter 8

Asymmetries during running in male youth

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Harrison, C., Ikhwan Nur, M., Sharil, M., Oliver, J. L., Hughes, M. 2012. Asymmetries during running in male youth. *Physical Therapy in Sports*, - paper under 2nd review.

8.1 Prelude

The long-term athlete development process and possible success of athletes on a world stage in senior years are dependent on many variables. Therefore, it seems essential to minimise all potential threats that prevent the athletes from training and competition, such as injuries. Normally, injuries will rise with increasing age and especially the age around peak height velocity (PHV), when changes in maturation are the greatest a noticeable increase in injury occurs. Therefore, it is essential to screen for possible injury threats such as leg asymmetries in the long-term athlete development process, and if possible, in a main motor performance of the athletes' sport, such as sprint running. Variables identified in the previous chapter contributing to maximal sprint running performance, such as power, horizontal and vertical force, are variables that can be used in the screening process to detect leg asymmetry or imbalance. As changes with growth and maturation were seen to affect those variables (especially from pre- to mid-PHV), it might be plausible that the asymmetry in those variables will vary/change through growth and maturation. However, whether this is the case or not is unknown. Therefore, the purpose of this study was to quantify the magnitude of asymmetry in a number of variables during a running task in male youths of different maturity status.

8.2 Introduction

With every training session and competitive event, athletes are at risk of injury. To decrease the likelihood of athlete injury, coaching staff implement various types of screens to identify possible risk factors. One possible risk factor identified in the literature is lower limb asymmetry, which has been proven to impact the incidence of injuries (Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002; Knapik, Bauman, Jones, Harris, & Vaughn, 1991; Orchard, Marsden, Lord, & Garlick, 1997; Yamamoto, 1993).

Testing for leg asymmetry can be performed utilising acyclic and cyclic methods. Acyclic asymmetries are usually quantified via a unilateral jumping task such as a vertical or horizontal jump (Flanagan & Harrison, 2007; Hoffman, Ratamess, Klatt, Faigenbaum, & Kang, 2007; Impellizzeri, et al., 2007; Newton, et al., 2006) or dynamometers (Croisier, et al., 2002; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Newton, et al., 2006; Orchard, et al., 1997; Rahnama, Lees, &

Bambaecichi, 2005). Cyclic assessments used to determine the magnitude of asymmetry have included: consecutive jumping (Flanagan & Harrison, 2007) and running assessments (Bachman, Heise, & Bressel, 1999; Belli, Lacour, Komi, Candau, & Denis, 1995a; Brughelli, Cronin, Mendiguchia, Kinsella, & Nosaka, 2010; Dalleau, Belli, Bourdin, & Lacour, 1998; Vagenas & Hoshizaki, 1992) performed on motorised and non-motorised treadmills and force plates.

With regards to cyclic assessments, the asymmetry associated with a variety of variables whilst jumping and running has been reported. Differences of 1.3 – 4.2% for flight time, reactive strength index, vertical stiffness and peak vertical force have been reported for consecutive jumping (Flanagan & Harrison, 2007). Leg asymmetries of 3.5% for contact time (Brughelli et al., 2010), 4.2 – 16.7% for leg stiffness (Bachman et al., 1999; Brughelli et al., 2010; Dalleau et al., 1998), 6.5 – 12.6% for vertical stiffness (Bachman et al., 1999; Brughelli et al., 2010), 0.9% for negative work (Dalleau et al., 1998), 10.7% for positive work (Brughelli et al., 2010), 1.1 - 3.7% for step time (Belli, Lacour, Komi, Candau, & Denis, 1995b), 3.7 - 11.6% for displacement (Belli et al., 1995b; Brughelli et al., 2010; Vagenas & Hoshizaki, 1992), and 46.3% (Brughelli et al., 2010) have been reported whilst running.

All the research discussed thus far has quantified the magnitude of asymmetry in adult participants. With the increase in elite sports academies in schools and many clubs identifying and developing talent at an early age, it would seem logical to screen developing athletes for leg asymmetries as well. The testing should preferably involve the main activity of the sports, such as running for football or field-hockey or jumping for volleyball, netball or basketball. However, studies quantifying asymmetry in children and/or youth athletes (Chin, So, Yuan, Li, & Wong, 1994; Teixeira, Silva, & Carvalho, 2003; Teixeira & Teixeira, 2008) are rare, and no researchers to the author's knowledge have quantified asymmetry whilst running in youths. Certainly asymmetry has not been investigated with regard to youth athletes of different maturity status. This would seem important given the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around (PHV) and the large improvements in strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990), and consequently power output (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero et al., 1990). In addition to and inherent with those changes in physical performance, it is thought that muscle and ligaments cannot keep pace with bone growth especially around the athlete's growth spurt , causing decreased flexibility and muscle imbalances (d'Hemecourt, Zurakowski, Kriemler, & Micheli, 2002; Purcell & Micheli, 2009), which in turn can increase incidence of injury, as evidenced in youth soccer players (Le Gall, Carling,

& Reilly, 2007). Given this information, the purpose of this study was to quantify the magnitude of asymmetry in a number of variables during a running task in male youths of different maturity status.

8.3 Methods

8.3.1 Participants

One hundred and twenty-two male athletes between 8 and 16 years of age volunteered to participate in this study. All participants were physically active, trained a minimum of two times per week for their sport, represented their club and/or school at a regional and/or national level and were involved in sports (soccer, field hockey, sprinting, distance running) where running/sprinting was a important component of their performance. The participants were further divided into three maturational groups (Rumpf, Cronin, Pinder, Oliver, & Hughes, 2012). The first group consisted of the pre-pubescent (≤12 years of age = pre-peak height velocity PHV), the second of the mid-pubescent (13-15 years of age = mid-PHV) and the last of the post-pubescent (≥16 years of age = post-PHV) athletes. Participant characteristics can be observed in table 8.1.

Table 8.1. Characteristics (mean ± SD) of participants across groups

	Age (years)	**Maturation offset (years)**	**Height (cm)**	**Mass (kg)**	**BMI (kg/m^2)**
Pre PHV (N = 41)	10.5 ± 1.37	-2.95 ± 0.92	141 ± 7.85	36.2 ± 10.2	17.9 ± 3.48
Mid PHV (N = 30)	14.6 ± 0.93	0.36 ± 0.52	166 ± 6.93	55.2 ± 6.59	19.4 ± 4.19
Post PHV (N = 51)	15.4 ± 0.74	1.79 ± 0.56	178 ± 8.22	70.4 ± 13.3	22.3 ± 3.55

All participants and their legal guardians were informed of the risks and benefits of participation and both legal guardians and participants provided written informed consent and assent to participate in this study. Procedures were approved by the Ethics Committee of AUT-University.

8.3.2 Equipment

Running performance was assessed using a non-motorised force treadmill (NMT) (Woodway, Weil am Rhein, Germany) in conjunction with the Pacer Performance Software (Fittech, Australia). The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a horizontal load cell (Model BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), which measured horizontal force. The height of the load cell was adjusted accordingly to the subject's height, so that the tether was horizontal during testing. Vertical force was measured by four individual vertical load cells that were mounted under the running surface. The entire system was calibrated using a range of known weights. Vertical and horizontal force were collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), and analysed with the Pacer Performance software (Fitness Technology, Adelaide, Australia).

8.3.3 Procedures

Data collection sessions were standardised around mode of training and daily structure. Before physical testing, anthropometric measurements were taken. The height (cm), sitting height (cm), mass (kg) were measured and the body mass index (BMI) calculated. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al. (2002): Maturity Offset = -9.236 + (0.0002708 × leg length × sitting height) + (-0.001663 × age × leg length) + (0.007216 × age × sitting height) + (0.02292 × weight by height ratio). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. The standard error of estimate for PHV was 0.49 years for boys (Mirwald et al., 2002).

Participants then received a familiarisation session on the non-motorised treadmill, which consisted of standing, walking and running at a self-chosen speed. The familiarisation was also used as a warm-up phase (~10 minutes). If the participants were unable to run freely, without holding on to the frame of the treadmill, the data collection was postponed and further familiarisation took place. Otherwise, a series of warm-up sprints on the treadmill i.e. 3 x 5 seconds preceded the data collection. The fastest two from three sprints over a 30 m distance from a standing split start were then collected and used for data analysis. A four minute rest was scheduled after each trial.

8.3.4 Data analysis

While vertical and horizontal forces were measured directly, average leg asymmetries (average power and average work) were calculated. Power was calculated by multiplying the instantaneous horizontal force by the instantaneous velocity. Work was calculated by horizontal force multiplied with displacement for each sample. Values were calculated for all steps during the 30 m sprint and then averaged for each leg. Percent asymmetry was defined as:

$$((\text{Left leg} - \text{right leg})/\text{right leg}) \times 100 = \%\text{asymmetry}$$

8.3.5 Statistical analysis

Means and standard deviation for all mentioned variables were calculated and used as measures of centrality and spread of data. A one-way analysis of variance (ANOVA) as well as Tukey post hoc contrasts were used to detect statistical difference in the variables of interest across the three maturational groups. Statistical significance was set at an alpha level of 0.05.

8.4 Results

The values for the variables of interest in this study can be observed in table 8.2. All variables increased in magnitude with maturation, the largest increases noted in work (205%) and power (252%).

Table 8.2. Mean, SD and percent difference between legs for subjects of different maturation status

	Pre-PHV	Mid-PHV	Post-PHV
	Mean ± SD	Mean ± SD	Mean ± SD
Horizontal force left (N)	91.6 ± 17.4	127.4 ± 17.3	150.4 ± 24.9
Horizontal force right (N)	88.3 ± 18.6	131.3 ± 20.1	152.1 ± 24.0
%difference	15.4 ± 14.2	14.8 ± 10.9	14.7 ± 14.3
Vertical force left (N)	395 ± 124	547 ± 113	657 ± 135
Vertical force right (N)	360 ± 131	507 ± 94.0	693 ± 145
%difference	18.1 ± 15.6	20.2 ± 16.8	20.8 ± 15.8
Power left (W)	274 ± 69.5	504 ± 92.6	666 ± 143
Power right (W)	264 ± 79.6	529 ± 106	691 ± 143
%difference	14.9 ± 14.6	15.8 ± 10.9	15.5 ± 14.7
Work left (J)	69.1 ± 20.7	114 ± 25.1	140 ± 28.8
Work right (J)	68.9 ± 24.9	116 ± 29.3	145 ± 32.4
%difference	*26.4 ± 19.9	14.7 ± 10.7	17.3 ± 16.1

*significant different from mid- and post-PHV ($p < 0.05$)

The cyclic asymmetries observed during the 30 m sprint on the non-motorised treadmill ranged from 14.7% to 26.4% as can be observed in table 8.3. When averaged across maturation, asymmetries in horizontal force (15.0%) were found to be significantly ($p < 0.05$) smaller than vertical force (19.7%) and work (19.5%). Furthermore, asymmetries in vertical force were significantly greater than in power (15.4%).

In terms of the between group comparisons for each of the dependent variables, the only variable found to differ significantly between maturity levels was work, the observed asymmetries in the pre-PHV group were substantially greater (26.4% ± 19.9) than the other two maturity groups (14.7 ± 10.7 and 17.3% ± 16.1).

8.5 Discussion

Inter-limb differences in non-injured youths ranged from 14.7 to 26.4% in the variables of interest whilst running on a non-motorised treadmill. These differences seem high compared to the only other study that has measured asymmetry whilst running on a non-motorised treadmill. Brughelli et al. (2010) reported imbalances of 1.6, 4.9, and 10.7% for vertical forces, horizontal forces, and work in non-injured Australian Football League players measured at 80% of maximum speed respectively. It is difficult to make direct comparisons between these studies as the running protocols used to determine asymmetry differ, however, it seems that there is substantially greater asymmetry in youths. This may be attributed to the greater movement variability and/or the physiological/physical differences associated with maturation (Armstrong et al., 2001; Armstrong et al., 2000; Forbes et al., 2009; Ioakimidis et al., 2004; Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). However, this contention is somewhat speculative and research is needed that compares the youth and mature athlete utilising the same equipment and protocols.

Substantial increases in hormone levels (Forbes et al., 2009; Fraisier et al., 1969; Kraemer, 1988; Ramos et al., 1998; Round et al., 1999) and anthropometric factors (height, weight, muscle mass, etc.) are associated with puberty, and subsequently large improvements in strength (Mero et al., 1990), and consequently power output (Armstrong et al., 2001; Armstrong et al., 2000; Forbes et al., 2009; Ioakimidis et al., 2004; Mero et al., 1990) are known to occur and therefore may challenge coordinated force production and sprint capability, and may in turn affect asymmetry of athletes of different maturity status. The inter-group comparisons for the most part revealed no significant differences between maturation groups in the variables of interest with the exception of work where pre-PHV participants were found to differ ($p < 0.05$) to the mid and post-PHV participants. As work is the product of force and distance, and since horizontal force asymmetries did not significantly differ across maturation groups, we speculate that the distance covered with each step (the distance travelled between alternating foot contacts) becomes more stable with age and maturation. That is, improvement in inter-limb coordination and its influence on step length may explain the differences between maturity groups.

Another finding was that the asymmetries varied significantly according to the variable used. That is, when averaged across maturation groups vertical force (19.7%) and work (19.5%) were significantly greater than horizontal force asymmetry (15.0%). Thus asymmetry seems to be directional and variable specific, our findings supporting those of Hewitt et al. (2011) who found asymmetries to differ significantly ($p = 0.02$) for vertical force (3.1%) as compared to power (9.2%) for an acyclic jumping task.

It needs to be acknowledged that there are limitations to this study. First, our participants were characterized as athletic or trained and therefore do not necessarily mirror a general population. Second, to calculate true running asymmetry, athletes should have performed over-ground running and their foot strikes recorded by a number of force plates laid in series. However, this methodology is impractical for most laboratories due to the financial outlay required to lay a series of in-ground force plates. It would seem therefore that a non-motorised treadmill provides a relatively inexpensive and practical alternative to measure the kinetics and asymmetries whilst running/sprinting. We represented asymmetry over 30 metres, however it may be that these asymmetries differ during different phases of the sprint (acceleration, maximum velocity, and/or deceleration) or at steady state running e.g. 80% of maximum velocity. Finally, the analysis of the kinetics was limited by the manufacturer's software and documenting asymmetry in other variables such as leg or vertical stiffness might have been of interest also.

8.6 Conclusions

This was the first study to quantify the magnitude of leg asymmetry during running in youth athletes across different maturation groups. It was thought that asymmetry might differ across maturation given the growth spurt around mid-PHV and associated adolescent awkwardness. Only the asymmetry of one variable (work) was found to differ significantly between groups and interestingly the greatest asymmetry was found in the pre-PHV and not the mid-PHV group. However, it would seem that for the most part that the magnitude of asymmetry is similar between maturation groups performing a running task on a NMT. Given this finding it would seem unnecessary to determine maturation in a youth sample. Furthermore, even though there are periods of accelerated growth and structural changes within the body, it would seem they have little effect on the measures of asymmetry used in this study.

With regards to the magnitude of asymmetry expected when using a NMT with a youth population, on average asymmetries of 17% (95% CI 13.2 lower bound and 21.6% upper bound) are not unusual in non-injured youth athletes whilst performing a running task. It needs to be noted that the data presented in this study is averaged data and some individuals are characterized by greater asymmetry (e.g. horizontal force = 46%) as evidenced by the large standard deviations observed for the variables of interest. The reader needs to be cognisant that individual player asymmetry is masked when data is presented in such a manner. Therefore, data should remain individualized when assessing athlete strengths and weaknesses for diagnostic and prognostic purposes.

Future research needs to determine if cyclic and acyclic asymmetries are similar in magnitude. If this is true leg asymmetry may be dependent upon the movement task being performed and then functional movement assessments as well as training programs must address movements that are specific to the athletic task of interest. If in doubt, it may be best to develop an acyclic single-leg multi-directional leg power and asymmetry profile as well as a cyclic running profile, which would provide information that drives the individualization of programming.

8.7 Acknowledgement

We would like to thank Abas Kasim from the Lai Meng School in Malaysia and Rob Taylor the sports coordinator from the Westlake Boys High school in New Zealand for their co-operation and enabling data collection to occur. We would also like to acknowledge the help from the staff of the National Sport Institute of Malaysia during testing.

Chapter 9

Acute effects of sled towing on sprint time in male youth of different maturity status

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. Acute effects of sled towing on sprint time in male youth of different maturity status. *Pediatric Exercise Science*, - paper under review.

9.1 Prelude

Previous studies have for the most part sought to improve understanding around the determinants of sprint performance in youth across different maturity groups. It is also important to understand how different training methods may affect the variables of interest and/or sprint performance. It is quite likely that different training methods will have different adaptational effects, dependent on the maturation of the athlete. Of interest in this study, are the effects of resisted sprint training e.g. sled towing. The adaptational effects of resisted sprint training are no doubt influenced by the magnitude of the load towed by the athletes. The effect of load has been investigated extensively in adults and it has been recommended that loads that enable participants to remain within 10% of their maximal velocity be utilised. However, the effect of load and such recommendations has not been investigated in youth populations. The purpose of this study therefore was to quantify the acute effects of different loads whilst sled towing on sprint time in pre- vs. mid-/post-PHV participants.

9.2 Introduction

Running is a fundamental movement for human beings and its fastest form, sprinting, is a pre-requisite to success in many sports. Given the importance of sprint speed, a number of training methods have been utilised to develop this motor quality. One such method is resisted sled towing, which has been utilised in the training of adult populations (Clark, Stearne, Walts, & Miller, 2010; Harrison & Bourke, 2009; Kafer, Adamson, O'Conner, & Faccioni, 1994; Kristensen, van den Tillaar, & Ettema, 2006; Spinks, Murphy, Spinks, & Lockie, 2007; Zafeiridis et al., 2005) with trivial (Clark et al., 2010) to very large (Zafeiridis et al., 2005) effect sizes observed in these studies. However, the utilisation of this type of training in youth populations has not been documented to the knowledge of these authors.

Prior to using resisted sled towing in training, it is necessary to understand how the load may affect sprint kinematics. For example, sled towing has been shown to change stride kinematics (Letzelter, Sauerwein, & Burger, 1995; Lockie, Murphy, & Spinks, 2003; Maulder, Bradshaw, & Keogh, 2008) significantly (Lockie et al., 2003; Maulder et al., 2008) in adults. The loads used in these studies were characterized as absolute (e.g. 2.5 kg) or relative (e.g. 10% of body mass). Loads of

2.5, 5, and 10 kg, decreased sprint time by 8.6, 12.6, and 23.4% respectively (Letzelter et al., 1995) in female sprinters. A relative load of 10, 12.6, 20, and 32% decreased sprint speed significantly ($p < 0.05$) by 7, 8.8, 12 and 22.8% respectively (Lockie et al., 2003; Maulder et al., 2008). Whether such decrements are similar in youth athletes and similar across athletes of different maturity status, is unknown. The purpose of this study therefore, was to investigate the acute effects of different sled towing loads on sprint times of youth athletes of different maturity status.

9.3 Methods

9.3.1 Participants

A total of 35 children participated in the study, consisting of 19 categorised as pre-peak height velocity (PHV) (age 10.5 ± 1.12 years, height 141 ± 9.54 cm, mass 38.4 ± 14.0 kg, maturity offset -3.01 ± 0.96 years from PHV), and the remaining 16 classified as mid-/post-PHV (age 15.2 ± 1.44 years, height 172 ± 4.52 cm, mass 60.9 ± 6.15 kg, maturation offset 1.22 ± 0.93 years from PHV). All participants were physically active and trained a minimum of two times per week in their sport and representing their school on a state and/or national level. The participants and their parents/legal guardians were informed about the potential risk involved with the study and gave written consent to participate. The investigation was approved by an university ethics committee.

9.3.2 Study design

A total of 35 developmental athletes were used to determine the effect of different load (2.5, 5, 7.5 and 10% body mass) sled towing on 30 metre sprint times. In order to achieve this, participants sprinted three times in unloaded and each of the loaded conditions and results were compared across each condition. In addition, a linear regression analysis was used to describe the effect of load on sprint times across respective populations.

9.3.3 Procedures

Participants were assessed on two separate occasions, with two days between assessments. On the first day of testing, anthropometric measurements were taken before the warm-up session. The height (cm), sitting height (cm), weight (kg) were measured and the body max index (BMI) calculated. The maturity status of participants, a maturity index (i.e. timing of maturity) was calculated using the following equation: Maturity Offset = -9.236 + (0.0002708 × leg length × sitting height) + (-0.001663 × age × leg length) + (0.007216 × age × sitting height) + (0.02292 × weight by height ratio) (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). This technique is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. Generally, athletes can be categorised into 3 groups as followed: pre-PHV velocity (-3 years to -1 years from PHV), around PHV (-1 to +1 years from PHV) and post-PHV (+1 to +3 years from PHV) (Rumpf, Cronin, Oliver, & Hughes, 2012).

However, as the number of participants was too small in the mid-PHV group, the mid-PHV and post-PHV participants were grouped together. The standard error of estimate for peak height velocity (PHV) is 0.49 years for boys (Mirwald et al., 2002).

After a warm-up, consisting of jogging, stretching and warm-up accelerations runs, the participants sprinted for 30 metres on a natural dry grass surface for three times to determine their average unloaded sprint time over 30 metres, measured with Swift double beam timing gates (SWIFT Performance Equipment, Wacol, Australia). Thereafter using a randomized approach, participants sprinted with an additional 2.5, 5, 7.5, and 10% of their body mass utilising custom made sleds, attached to harnesses from SPEEDY sled equipment (Sport Pawlik, Unterkirnach, Germany). On the first day of testing and after the unloaded sprints, two sets of loaded sprints occurred and the remaining two sets occurred on the second testing day after participants received the identical standardised warm-up. A total of three sprints were performed at each load with a recovery of at least 180 seconds between each sprint. Average values of three runs in the unloaded and each of the loaded conditions were used for further data analysis.

9.3.4 Statistical analysis

Three trials for each load condition were averaged for an individual participant mean, and participants' means for each load condition were averaged to provide a group mean. A two factor [group (2) × load (4)] repeated-measures ANOVA (SPSS, IBM, NY, USA) with Bonferoni post hoc contrasts was used to determine whether there was a significant difference in sprint times. Trend lines were fitted to the load effects over sprint time for both the pre- and mid/post-PHV data. Linear regression equations and goodness of fit (R^2) scores were generated using Microsoft Excel 2007 (Microsoft Corporation, Albuquerque, NM, USA). An independent t-test was used to determine if the slopes of the regression equations differed significantly. Percent changes for each load in both groups were also calculated from the regression equations. An alpha level of $p = 0.05$ was chosen as the criterion for significance.

9.4 Results

Averaged sprint data for the two groups for unloaded and all loaded conditions can be observed in table 9.1.

Table 9.1. Thirty metre sprint time data (mean ± SD) for all groups across all conditions

	unloaded	**2.5%**	**5%**	**7.5%**	**10%**
Pre-PHV	5.69 ± 0.34	*#5.97 ± 0.35	*#6.18 ± 0.41	*6.37 ± 0.41	*6.59 ± 0.54
Mid-/post-PHV	4.33 ± 0.17	*#4.52 ± 0.20	*#4.61 ± 0.21	*4.67 ± 0.24	*4.76 ± 0.25

* significant different from unloaded condition $p < 0.05$
# significant different from all other conditions $p < 0.05$

Thirty-metre sprint times ranged from 5.69 to 6.59 s for pre-PHV and 4.33 to 4.76 s for mid/post-PHV athletes across the 0-10% body mass loads. The older athletes were significantly ($p < 0.05$) faster across all loads (average of 33% ranging from 31-39%). In terms of the within group comparison the pre-PHV participants were slower by 3.02% on average with each 2.5% incremental load while the mid/post-PHV participants were less affected and increased sprint time by 2.25% on average with each load. Each load resulted in a significant increase in sprint times in both groups except for loads of 7.5 to 10%. The percent decrease in sprint times as a function of body mass as well as the regression equations for the lines of best fit can be observed in figure 9.1.

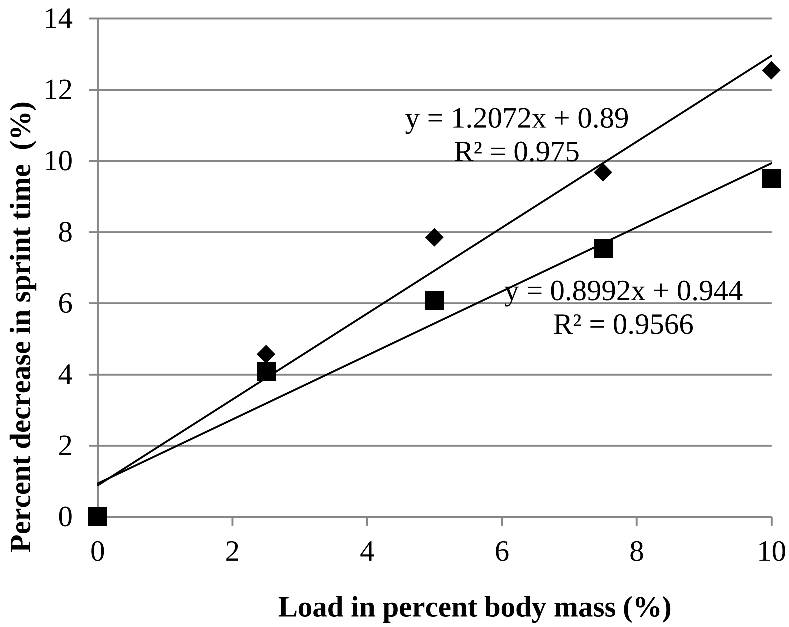

Figure 9.1. Decrease in sprint time (%) as a function of load body mass (%) for pre-PHV (♦) and mid/post-PHV participants (■)

With regards to the between group analysis, it needs to be stated that there was no significant group × load interaction observed ($p = 0.056$) from the ANOVA. However, given the interaction was approaching significance the slopes of the regression equations for pre- vs. mid-/post-PHV participants were compared and they were found to be statistically different ($p < 0.004$).

9.5 Discussion

The primary purpose of this study was to investigate the acute effects of different sled loads on sprint times in different maturation status. Not surprisingly, the between group comparison of sprint times at different loads revealed that mid-/post-PHV participants were significantly faster (~33% on average) over 30 metres in all conditions compared to the pre-PHV participants. In both groups, a load of 2.5% was sufficient to change sprint time over 30 metres significantly and furthermore all subsequent loads differed significantly from one another except for loads 7.5 and 10%. Comparisons with other research is difficult given all subjects are adults; Lockie et al. (2003) reported velocity decrements of 8.7% and 22.8% over a 15 metre distance for 12.6% and 32.2% body mass loads respectively. Maulder et al. (2008) used loads of 10 and 20% of body mass over a 10 metre distance from a block start and reported an increase in sprint time of 8 and 14% respectively, as compared to the unloaded condition.

Of interest was whether athletes of different maturation status responded the same to resisted sprint loads. Each incremental load (i.e. 2.5% body mass) was found to reduce 30 metre sprint times by ~3% and ~2.3% for the pre- and mid-/post-PHV respectively. It would seem that the older athletes were less affected by the same relative load. Given the group × load interaction was approaching significance (p =

0.056) and a comparison of the slopes of the regression equations was found to be significantly different, this contention seems somewhat supported.

The regression equations generated enable the prediction of the effects of load on the sprint performance of youth athletes. The equations are maturation specific, the differences in the effect of load magnified at heavier relative loads. For example, a 6% body mass load resulted in an 8.1% increase in sprint time for pre-PHV athletes, whereas an 8% body mass load was needed to produce the same increase in sprint time in mid-/post-PHV participants.

Chapter 10

The effect of resisted sprint training on running performance in youth

This chapter comprises the following paper:

Rumpf, M. C., Cronin, J. B., Oliver, J. L., Hughes, M. 2012. The effect of resisted sprint training on running performance in youth. *Pediatric Exercise Science*, - paper under review.

10.1 Prelude

Resisted type sprint training (e.g. sled towing) is a specific training method that has been utilised to improve sprint running performance in adults. The previous chapter improved our understanding of the acute effects of load on sprint performance. However, the efficacy of resisted type sprint training for improving sprint performance in youth is unknown. Furthermore, it may be that this type of training has differential effects, depending on the maturity of the athletes. That is, it has been shown that strength training may be better used for post-PHV youth. The purpose of this study therefore was to investigate the effects of resisted sled towing on the sprint performance of youth of different maturity status.

10.2 Introduction

Sprinting is an essential component of performance in many sports. Therefore finding the best methods to increase speed in developmental as well as elite athletes is of interest to coaches as well as sport scientists. With regards to the developmental athlete, improvements in sprint performance have been reported through sprint training (Kotzamanidis, 2003; Venturelli, Bishop, & Pettene, 2008), strength and plyometric training (Chelly et al., 2009; Christou et al., 2006; Coutts, Murphy, & Dascombe, 2004; Diallo, Dore, Duche, & van Praagh, 2001; Faigenbaum et al., 2007; Kotzamanidis, 2006; Kotzamanidis, Chatzopoulos, Michailidis, Papalakovou, & Patikas, 2005; Meylan & Malatesta, 2009; Thomas, French, & Hayes, 2009; Wong, Chamari, & Wisloff, 2010) and combined (Faigenbaum et al., 2007; Ingle, Sleap, & Tolfrey, 2006; Kotzamanidis et al., 2005; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010; Mujika, Santisteban, & Castagna, 2009; Tsimahidis et al., 2010) training methods.

What is obvious from the literature is that there are many training methods to develop running speed, one such method is resisted sprint training, which is of interest to researchers. In terms of resisted sprint training, six training methods have been used in the training of adults: towing weights (Clark, Stearne, Walts, & Miller, 2010; Harrison & Bourke, 2009; Kafer, Adamson, O'Conner, & Faccioni, 1994; Kristensen, van den Tillaar, & Ettema, 2006; Spinks, Murphy, Spinks, & Lockie, 2007; Zafeiridis et al., 2005), wearing weighted vests or belts (Clark et al., 2010), adding weight to distal limb segments (Smirnov, 1978), pulling a parachute (Alcaraz, Palao, Elvira, & Linthorne, 2008), running up-hill (Paradisis & Cooke, 2006) and resisted treadmill sprinting (Ross et al., 2009). As can be observed, the most frequently researched resisted sprint training method in adults is towing weights, also described as resisted sled towing. Despite the fact this technique is frequently used in the training of adults, there is no empirical evidence as to the suitability and efficacy of resisted sled towing in a youth population.

With regard to speed development in youth, it may be that young athletes, particularly in post-pubescent state benefit more (compared to pre- and/or mid-pubescent) from resisted type sprinting. For example, it has been shown that strength (Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990) and power (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Mero et al., 1990) are affected by maturation, which may in turn affect speed. The improvements in strength and power has been attributed to the rise of hormone levels (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004) (testosterone and growth hormones) associated with puberty (Forbes et al., 2009; Fraisier, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around peak height velocity (PHV). Therefore, the age at which PHV occurs, typically between the chronological age from 12-15 years

(Balyi & Way, 2005) and the onset of puberty (Malina, Bouchard, & Bar-Or, 2004), maybe significant in the development of sprint performance. It has been suggested that the interaction of structured training and growth represents a time where training is thought to be most efficient (Borms, 1986; Viru et al., 1999) and consequently this time frame has been termed “window of accelerated adaptation to training” or “window of trainability” (Balyi & Way, 2005). It may be suitable during this period of development to focus training on strengthening to enhance power output and consequently running speed. However, there is only limited knowledge supporting this theory. A recent meta-analysis of resistance training in children and adolescents (Behringer, Vom Heede, Yue, & Mester, 2010), examined the efficacy of resistance training across a variety of age and maturation groups. The authors concluded that gains in strength were more pronounced in late maturation, however, populations categorised into pre-pubescent also benefited from resistance-training. Consequently, it would be plausible for pre-pubescent participants to gain benefits in sprint performance from resisted training as well.

Given that no study has investigated the effect of sled towing on sprint performance in youth, the purpose of this study was to determine the efficacy of resisted sled training on the kinematics and kinetics of maximum sprint performance in male youth of different maturation status. Such analysis may provide information about appropriate training methodology in relation to maturation and windows of trainability for speed development.

10.3 Methods

10.3.1 Experimental approach to the problem

A total of 32 participants between 9 and 17 years of age volunteered to participate to determine the effect of resisted sled towing training on 30 m sprint performance. In order to achieve this, athletes participated in a total of 16 sessions of resisted sled towing sprinting over a 6 week period, with 2-3 sessions per week. Before and after the training programme, participants were tested on three 30 metre sprints on a non-motorised treadmill, which measured sprint kinetics and kinematics.

10.3.2 Subjects

A total of 32 children volunteered to participate in the study, with 14 subjects categorised as pre-peak height velocity (PHV), and the remaining 18 categorised as mid- or post-PHV. All participants' characteristics and their training attendance can be observed in table 10.1.

Table 10.1. Participants' characteristics (mean ± SD) and training attendance for both groups

	Pre-PHV (n=14)	Mid-/post-PHV (n=18)
Age (years)	10.4 ± 0.77	15.2 ± 1.57
Maturation offset (years from PHV)	-3.16 ± 0.80	1.32 ± 0.95
Height (cm)	141 ± 7.93	173 ± 5.32
Body mass (kg)	38.2 ± 15.6	62.7 ± 11.0
Leg length (cm)	69.0 ± 4.05	82.9 ± 3.67
Adherence to training (# of sessions)	11.6 ± 2.03	13.8 ± 1.64

Note. All variables significantly different between groups

All participants were physically active and trained a minimum of two times per week in their sport. The participants and their parents or legal guardians were informed about the study and gave written consent to participate. The investigation was approved by the institutional Ethics Committee of AUT University.

10.3.3 Procedures

Anthropometric measurements were taken before the familiarisation session on the non-motorised treadmill. The height (cm), sitting height (cm), and mass (kg) were measured. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald et al. (2002): Maturity Offset = -9.236 + (0.0002708 × leg length × sitting height) + (-0.001663 ×

age × leg length) + (0.007216 × age × sitting height) + (0.02292 × weight by height ratio). This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. The standard error of estimate for PHV was 0.49 years for boys (Mirwald et al., 2002).

Participants then received a familiarisation session on the non-motorised treadmill, which consisted of standing, walking and running at a self chosen speed. Those steps were also taken as a warm-up phase (~10 minutes) if the participants felt safe and were able to run without using their hands holding on to the frame of the treadmill. If the participants were unable to run freely, the data collection was postponed. Otherwise, a series of warm-up sprints on the treadmill i.e. 3 x 5 seconds preceded the initial data collection. The mean value of three runs of a 30 metre distance from a standing split start was used for data collection. The participants recovered completely after each trial with at least 4 minutes between each run. The effect of training was evaluated in tests performed prior to (week 1) and after (week 7) the 6-week training intervention.

A non-motorised force treadmill (Woodway, Germany) was used to measure variables of interest during a 30 metre sprint. The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a horizontal load cell (Model BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), which measured horizontal force. The height of the load cell was adjusted accordingly to the subject's height, so that the tether was horizontal during testing. Vertical force was measured by four individual vertical load cells that were mounted under the running surface. The system was calibrated using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), and analysed with the Pacer Performance software (Fitness Technology, Australia).

10.3.4 Training

The intervention consisted of 6 weeks of resisted sled towing training, with 2-3 sessions per week and a total of 16 sessions. The initial five minutes of every training session were used for a standardised warm-up, which consisted of jogging, running, dynamic stretches of the leg muscles and warm-up accelerations runs. Custom made sleds with a total weight of 300 grams in conjunction with harnesses from SPEEDY (Sport Pawlik, Unterkirnach, Germany) sled equipment and weightlifting plates of different loads were used during training. Eight to ten sprints over distances from 15 to 30 metres with a load of 2.5, 5, 7.5, or 10% BM were performed in each session. The effect of these loads on sprint mechanics and performance were determined during piloting, and were deemed the best loads to progressively overload the youth athlete over the six weeks of training. The difference in %BM load applied on the sled and the true calculated load from the participants' BM was below 50 grams. The daily training volume (calculated by #sprints per distance × distance × load) was altered after each session by increasing the total distance covered for each session before the individual load. The progression in the training program can be observed in table 10.2.

Table 10.2. Training program

Session	Amount of sprints per session	Total distance (metre) per session	Total load per session (#sprint×load×distance)
1	8	140	525
2	8	160	525
3	8	160	650
4	8	180	650
5	8	180	775
6	8	200	775
7	8	200	900
8	8	220	900
9	10	220	1025
10	10	240	1025
11	10	240	1150
12	10	260	1150
13	10	260	1275
14	10	280	1275
15	10	280	1400
16	10	300	1425

10.3.5 Data analysis

The majority of variables (sprint time, average velocity, average step rate, average and peak power, average and peak horizontal force, average and peak vertical force, average work) of interest were collected and analysed using a sampling rate of 200 Hz utilising the Pacer Performance software (Fitness Technology, Joondalup, WA, Australia). Dimensionless leg stiffness and dimensionless vertical stiffness were analysed with a custom designed Matlab (MathWorks, Inc., Natick. MA, USA) program. Dimensionless vertical stiffness was calculated from the maximum ground reaction forces during contact divided by the vertical displacement of the center of mass as described by McMahon and Cheng (1990). Vertical displacement was determined by double integration of the vertical acceleration (Cavagna, Franzetti, Heglund, & Willems, 1988) in the eccentric phase. Vertical acceleration was obtained from the peak vertical force divided by body mass after subtracting gravitational acceleration (Cavagna et al., 1988). Dimensionless leg stiffness was calculated as the maximum vertical force (F_{max}) divided by the peak displacement (Δ) of the initial leg length (L) (Morin, Dalleau, Kyrolainen, Jeannin, & Belli, 2005), calculated from standing height minus sitting height:

$$k_{leg} = F_{max} * \Delta L^{-1}$$

The peak displacement of the initial leg length was calculated as:

$$\Delta L = L - \sqrt{L^2 - \left(\frac{vt_c}{2}\right)^2} + \Delta y_c$$

where v = running velocity (in m × s^{-1}), t_c = contact time (in seconds) and Δy_c= the vertical displacement (in metres) of the center of mass when it reached its lowest point during mid-stance. Dimensionless leg stiffness and vertical stiffness derived from further multiplying the two stiffness measures with the initial leg length and then dividing the product by the participants' body mass multiplies with gravitational acceleration of 9.81 (McMahon & Cheng, 1990). Relative average and peak vertical force were calculated using the body mass of the participants.

Vertical, horizontal forces and running velocity were measured directly, via four individual vertical load cells that were mounted underneath the running surface, a horizontal load cell (Modell BS-500 Class III, Transcell Technology Inc, Buffalo Grave, USA), and two optical speed photomicrosensors in conjunction with a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia) respectively. Step length, step frequency and power were calculated. Variables were defined as followed:

Step length: Difference in distance from consecutive alternating feet

Step frequency: 1/contact time + aerial time of a step

Power: Horizontal forces × velocity

Work: Horizontal force × distance

Contact time: Time from initial foot touch-down until toe-off

Flight time: Time outside contact time

10.3.6 Statistical analysis

Means and standard deviation for all dependent variables of interest were used as measures of centrality and spread of data. Percent changes from pre- to post-training were calculated for every dependent variable [(1-post/pre-score) × 100]. Paired sample t-test were used to determine if the percent change in the dependent variables of interest differed significantly from pre- to post-testing for each maturation groups. Effect sizes (ES) were also calculated for each dependent variable and discussed based on the interpretation of negative/positive effects sizes according to Hopkins (Hopkins, 2009). The effect sizes of <-0.20, $\leq -0.20 > -0.60$, $\leq -0.60 > -1.20$, $\leq -1.20 > -2.00$, $\leq -2.00 > -4.00$ were categorised as trivial, small, moderate, large and very large respectively.

An analysis of covariance (ANCOVA) was used to detect differences in the percent change of dependent variables between groups by removing the variance of certain predictor variables (e.g. adherence to training), which were thought influential on the outcome variables of interest. An alpha level of $p < 0.05$ was chosen as the criterion for significance for all tests.

10.4 Results

As can be observed from table 10.1, age, height, leg length, body mass and maturation offset were significantly ($p < 0.05$) different between the pre- and post-PHV group. Averaged values for all variables of interest from pre- and post-training, the percent changes and effect sizes for both groups are reported in table 10.3.

Table 10.3. Sprint performance kinematics and kinetics (mean± SD), %change and effect statistics for pre- and mid-/post-peak height velocity participants in pre- and post-test

	Pre-peak height velocity (n = 14)					**Mid-/post peak height velocity (n = 18)**				
	Pre-training	Post-training	%change	Effect size		Pre-training	Post-training	%change	Effect size	
Sprint time (s)	10.1 ± 0.96	10.0 ± 1.02	-0.99	-0.10	Trivial	6.95 ± 0.54	*6.55 ± 0.44	-5.76	-0.74	Moderate
Average velocity (m/s)	3.00 ± 0.30	3.04 ± 0.30	1.33	0.13	Trivial	4.34 ± 0.34	*4.60 ± 0.32	5.99	0.76	Moderate
Average step rate (#/s)	4.17 ± 0.58	4.24 ± 0.56	1.68	0.12	Trivial	4.25 ± 0.45	*4.49 ± 0.29	5.65	0.53	Small
Average step length (m)	0.79 ± 0.15	0.78 ± 0.17	-1.27	-0.05	Trivial	0.99 ± 0.15	0.96 ± 0.15	-3.03	-0.20	Small
Average power (W)	282 ± 69.6	280 ± 68.6	-0.71	-0.03	Trivial	660 ± 136	*702 ± 134	6.36	0.31	Small
Peak power (W)	1026 ± 176	964 ± 206	-6.04	-0.35	Small	2156 ± 360	2228 ± 420	3.34	0.20	Small
Average horizontal force (N)	94.7 ± 14.3	93.7 ± 13.9	-1.06	-0.07	Trivial	155 ± 19.5	158 ± 18.9	1.94	0.15	Trivial
Peak horizontal force (N)	324 ± 20.9	318 ± 40.8	-1.85	-0.28	Small	495 ± 66.6	*543 ± 95.3	9.70	0.72	Moderate
Average relative vertical force (N/kg)	10.2 ± 1.40	9.93 ± 0.16	-2.65	-0.19	Trivial	9.86 ± 0.20	*10.2 ± 0.15	3.45	1.70	Large
Peak relative vertical force (N/kg)	29.0 ± 7.49	28.7 ± 6.82	-1.03	-0.04	Trivial	30.6 ± 3.29	29.9 ± 3.23	-2.29	-0.21	Small
Average work (J)	73.4 ± 24.8	72.3 ± 25.4	-1.50	-0.04	Trivial	145 ± 25.3	143 ± 28.4	-1.38	-0.08	Trivial
Contact time (s)	0.24 ± 0.02	0.24 ± 0.02	0.23	-0.14	Trivial	0.17 ± 0.01	0.17 ± 0.01	3.03	0.26	Small
Flight time (s)	0.28 ± 0.03	0.29 ± 0.02	5.80	0.42	Small	0.30 ± 0.02	0.29 ± 0.01	-2.43	-0.30	Small
Vertical displacement (cm)	5.36 ± 2.87	5.37 ± 2.16	0.19	0.40	Small	5.70 ± 0.99	*6.53 ± 1.72	14.6	1.46	Large
Vertical stiffness	32.9 ± 13.7	33.2 ± 13.8	0.91	0.02	Trivial	40.2 ± 9.21	*33.2 ± 6.75	-17.4	-0.76	Moderate
Leg stiffness	3.90 ± 0.99	3.88 ± 0.90	0.51	0.03	Trivial	10.9 ± 2.27	*6.00 ± 1.37	-45.0	-2.16	Very large

*significant different pre- vs. post-test

No significant changes were observed in the pre-PHV within group pre-post comparison (-6.04 to 1.68%, ES -0.35 to 0.12) in any variable after the training intervention. However, statistically significant reductions in sprint time leg and vertical stiffness (%change range = -5.76 to -45%, ES range -0.74 to -2.16) as well as increased average velocity, average step rate, average power, peak horizontal force, average relative vertical force and vertical displacement (%change range 3.45 to 14.6%, ES range 0.31 to 1.70) were observed in the mid-/post-PHV group post-intervention.

In terms of the between-group comparison, the percent changes from pre- to post training were significantly different (-11.3 to 11.1%) for sprint time, average velocity, average step length, peak power, peak horizontal force, relative vertical force, flight time, vertical displacement and leg stiffness when controlling for adherence to training (see table 10.4). The overall average in percent changes from pre- to post-training in those variables were 6.57% (± 3.76) for the mid-/post-PHV group and 3.26% (± 2.75) for the pre-PHV group.

Table 10.4. Adjusted %change in sprint performance kinematics and kinetics in pre- and mid-/post-PHV participants

Variable	Adjusted (mean ± SD) %change		Covariate
	Pre-Peak Height Velocity	Mid-/Post Peak Height Velocity	
Sprint time	-1.40 ± 1.16	*-5.52 ± 1.00	Adherence to training
Average velocity	1.55 ± 1.28	*5.81 ± 1.10	Adherence to training
Average step rate	7.04 ± 4.56	3.86 ± 3.93	Adherence to training
Average step length	-0.92 ± 5.26	*-0.74 ± 4.53	Adherence to training
Average power	0.60 ± 2.33	6.06 ± 2.01	Adherence to training
Peak power	-8.69 ± 4.71	*6.53 ± 4.06	Adherence to training
Average horizontal force	-0.19 ± 1.73	1.58 ± 1.49	Adherence to training
Peak horizontal force	-3.04 ± 4.34	*11.1 ± 3.74	Adherence to training
Relative vertical force	-2.05 ± 1.90	*3.81 ± 1.64	Adherence to training
Average work	-1.52 ± 5.55	0.46 ± 4.78	Adherence to training
Contact time	0.43 ± 2.55	2.88 ± 2.20	Adherence to training
Flight time	7.22 ± 2.87	*-3.54 ± 2.47	Adherence to training
Vertical displacement	-2.13 ± 7.85	*-10.8 ± 6.76	Adherence to training
Vertical stiffness	-2.13 ± 7.85	-10.8 ± 6.76	Adherence to training
Leg stiffness	2.31 ± 5.72	*-11.3 ± 4.93	Adherence to training

*significant difference between groups

10.5 Discussion

To the best of our knowledge this study was the first to investigate the effect of resisted sled towing training on sprint performance in youth. Therefore, comparisons with existing literature in youth are problematic and only possible with regards to research involving adults. The reader needs to be cognisant of this limitation.

The main finding of this study was that the resisted sled towing protocol produced a significant reduction in sprint time (-5.76%; ES = 0.74) or increase in average velocity (5.99%; ES = 0.76) in the mid-/post PHV group, whilst the training effect for the pre-PHV was trivial and non-significant (-0.99, 1.33%; ES = -0.10 and 0.13). The effects of resisted sprinting have been reported in adults (Clark et al., 2010; Harrison & Bourke, 2009; Spinks et al., 2007; Upton, 2011), after 4-8 weeks of training with a volume of 12-18 sessions utilising ~13% body mass sled load or a load that resulted in 10% speed reduction in male semi-professional athletes (Harrison & Bourke, 2009; Spinks et al., 2007) and male (Clark et al., 2010) and female collegiate athletes (Upton, 2011). All studies reported improvements in sprint performance after the training intervention (Clark et al., 2010; Harrison & Bourke, 2009; Spinks et al., 2007; Upton, 2011). Average ES for average velocity and sprint time in those studies were 0.26 to 0.51. Given the ES of the mid-/post-PHV participants (0.76, -0.74,) in this study, it seems that youth of this maturity status respond similar to if not better than adults when resisted sled towing is utilised as a training stimulus.

Given that velocity is the product of step length and step rate, it stands to reason that one, if not both, variables are responsible for the decreased sprint time or increased velocity in the Post-PHV group. It can be observed from the within group comparisons (see table 10.4) that the resisted sprint training resulted in a small non-significant reduction in step length and a significant increase (5.65%) in step rate. It would seem that increased step rates might be a potential benefit of resisted sled towing and better explain the increase in average velocity. Certainly, a greater reduction in step length as opposed to stride frequency with increasing load has been reported in cross-sectional studies (Cronin, Hansen, Kawamori, & McNair, 2008; Letzelter, Sauerwein, & Burger, 1995; Lockie, Murphy, & Spinks, 2003), indicating that step length is compromised to a greater extent by sled towing. It seems possible that after repeated application of this type of training, stride frequency supercompensates after unloading and is therefore the variable that better explains increases in average velocity.

The use of the non-motorised treadmill has enabled a number of other novel findings that allows some insight into some of the mechanistic adaptations to resisted sled towing. Unfortunately, none of the studies cited previously have provided information regarding the effects of resisted sled towing on other mechanistic variables and as a consequence the comparison of data from this study with other research, be it adult or youth, is problematic.

Other notable adaptations to the sled towing stimulus in the mid-/post-PHV group was the increase in peak horizontal force, which no doubt influenced the peak power measure, as power was calculated as the product of horizontal force and velocity. The increases in horizontal force and power are most likely best explained by the force vectors relative to the ground implicit in sled towing as indicated by the increase in trunk lean (Cronin & Hansen, 2006; Lockie et al., 2003). Interestingly, a large increase (3.45%; ES= 1.70) in average relative vertical force from pre- to post-testing in the mid-/post-PHV participants was also observed. It would seem that the resultant force vector associated with sled towing was of sufficient magnitude in the horizontal and vertical directions to elicit multi-planar adaptation.

Finally, it seems that sled towing resulted in significant reductions in vertical (-7.4%) and leg stiffness (-45%) in the mid-/post-PHV group. Given that vertical force did not change significantly in either group, this seems to suggest that sled towing had an increased effect on the rise and fall of the center of mass i.e. vertical displacement. This was certainly the case, a significant increase in vertical displacement (15.3%, ES= 1.46) was noted in the mid-/post-PHV group from pre~ to post-testing. A number of researchers have also reported increased ground contact times with increased sled loading (Cronin et al., 2008; Letzelter et al., 1995; Lockie et al., 2003). It maybe that these kinematic adaptations that result from increased sled loading when repeated over time, affect running kinematics and in turn variables such as stiffness.

Decreasing stiffness might be seen as a negative adaptation to resisted sled towing, as it supposedly would reduce the rate of force transmission between the legs and the ground and therefore acceleration and running speed (Arampatzis, Bruggemann, & Metzler, 1999; Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002). However, this does not seem the case in this study as faster velocities were achieved with decreased stiffness. Furthermore, Taylor and Beneke (2012) compared the stiffness characteristics of the three fastest men on earth. They found that even though Usain

Bolt achieved the greatest velocity over the 60–80 m split compared to his competitors, his estimated vertical and leg stiffness were significantly lower than his competitors. As a consequence, high stiffness seems to be not necessarily a pre-requisite to high sprint velocity.

10.6 Practical applications

Resisted sled towing is a form of sprint training that can be used to improve sprint performance in developing athletes. Training frequency of two times per week with total sprint distances of 140 – 300 metres will produce moderate sprint training effects in mid-/post-PHV athletes. It would seem that this type of training increases velocity via mechanistic changes including, increased step frequency, increased horizontal force and power production as well as decreased stiffness. Decreased stiffness however, might be viewed as disadvantageous in the long term in terms of fast force production. It might be that other resisted training methods such as adding a weighted vest might counteract the loss in stiffness by providing greater vertical eccentric overload as well as a more upright running posture. The ideal combinations and adaptations of such training methods are yet to be determined in both youth and adult populations.

10.7 Acknowlegement

We would like to thank the physical education teacher from the Lai Meng School Abas Kasim for his co-operation. He was a great help in realising the study. We would also like to acknowledge the help from the staff of the National Sport Institute of Malaysia during testing.

Chapter 11

Summary, practical applications and future research directions

11.1 Summary

A number of limitations of the research in this area were identified from the literature reviewed. Principally that: 1) there were no studies that had evaluated the kinematics and kinetics of sprint performance in male youth, especially pre-pubescent; 2) no research had investigated the reliability of these variables across maturity status; 3) there was a lack of research with regards to periods of accelerated adaptation for sprint running performance and possible training methods suitable for different maturity status; 4) research specifically investigating and quantifying the effect of specific and non-specific sprint training in male youth was limited; and, 5) no study had tracked the effect of resisted strength training on sprint performance in males of different maturity status. Consequently, a number of aims were identified which provided the focus for the thesis. Subsequent discussion in this section articulates the main findings of each the aims of the thesis:

Aim 1: Describe the most common tests and associated reliabilities used for assessing sprint running in youth. The first literature review investigated common tests and associated reliabilities used for assessing sprint running performance in youth. While over-ground sprinting over 30 metres using stop watches and timing gates was the most utilised method to assess sprint running performance, only a limited number of devices (force and non-motorised treadmill) were able to quantify step-by-step kinetics and kinematics variables. The utilisation of such devices was rare and the reliability of the variable used involving those devices was very limited and rarely reported especially with a youth population.

Aim 2: Review and quantify all training methods thought to improve sprint running performance in male youth with regard to different maturity status. The second literature review investigated the training methods thought to improve sprint running performance in male youth with regards to different maturity status. As there was a lack of knowledge in this area, we used all longitudinal studies which investigated some sort of training on sprint running performance in youth. We categorised the youth into pre-, mid- or post-PHV groups with regards to their chronological age and summarised the effect of specific (sprint training), non-specific (strength, plyometrics) and combined training on sprint running performance. It was observed that plyometric training was the most effective training methods in pre-PHV participants (ES = -1.46 ± 1.85, %change = -2.83 ± 0.50), followed by sprint training (ES = -0.57 ± 0.31, %change = -3.47 ± 1.27) and combined (ES = -0.52 ± 0.13, %change = -2.67 ± 0.67) training methods. However, the effect of resisted, assisted and strength and power, training on sprint times in pre-

PHV participants had not been investigated. Mid-PHV participants also benefited from plyometric training methods the most (ES = -0.57, %change = -2.04), followed by strength (ES = -0.30 ± 0.63, %change = -1.46 ± 2.42) and combined training (ES = 0.00, %change = 0.00). Training studies using specific sprint training methods involving mid-PHV participants were not found. Post-PHV participants sprint times benefitted most from combined training methods (ES = -1.33 ± 0.47, %change = -5.79 ± 2.54) followed by strength training (ES = -0.48± 0.58, %change = -2.26 ± 3.44). However, there was also a lack of research investigating the effects of specific sprint training methods, such as resisted sprint training in this population.

Aim 3: Investigate the reliability of kinematic and kinetic variables on a non-motorised treadmill in male youth athletes in pre-pubescent status. In order to understand any changes in sprint running performance over time, there is a need for reliable and valid protocols. The reliability of the kinematics and kinetics associated with maximal velocity over a 30 m sprint on a non-motorised treadmill was quantified. All variables were found reliable when the percent change in the mean and the coefficient of variation (CV < 10%) were considered. In terms of the intraclass correlation coefficient, three variables (vertical force, step rate and average horizontal force) failed to meet the reliability criteria i.e. ICC > 0.70.

The Pacer software associated with the non-motorised treadmill was unable to provide an in depth analysis of sprint running kinematics and kinetics, such as the step by step analysis of vertical and leg stiffness. In order to calculate those variables, processing the force signal from the non-motorised treadmill was essential. Chapter five investigated how different step detection thresholds influenced sprint kinetic and kinematics. It was found that a step detection threshold of 15% of the athlete's body mass was one of the lowest and most reliable thresholds, and therefore the recommended threshold to analyse sprint kinetics and kinematics on a non-motorised treadmill.

Aim 4: Investigate the kinematic and kinetic determinants of sprint running performance in male youth athletes in different maturity status. As mentioned previously, age and maturation were thought to influence running performance in the athlete's development process and therefore a cross sectional study investigated 30 m sprint performance in developing athletes of different maturity status. Speed, step length, step frequency, vertical and horizontal force, and horizontal power were significantly different (~8 to 78%, $p < 0.05$) in pre-PHV vs. mid- and post-PHV participants. However, only relative vertical force and speed differed significantly between mid- and post-PHV groups. The greatest average percent change in kinetics and kinematics over a 30 metre sprint on a non-motorised treadmill was observed from pre- to mid-PHV (37.8%) compared to mid- to post-PHV groups (11.6%). The two best predictors of maximal velocity across maturation were power and horizontal force (r^2 =97-99%), indicating the importance of the specific force direction whilst sprinting.

Additional information about leg and vertical stiffness and the contribution of the stretch-shortening cycle (SSC) were investigated in the ensuing chapters. Dimensionless vertical stiffness increased significantly ($p < 0.05$) across maturation, while dimensionless leg stiffness was significantly higher in post- compared to mid- (18.4%) and pre-PHV participants (44.5%).

Variables associated with SSC ability (eccentric and concentric mean power) were significantly different between pre- vs. mid- and post-PHV participants (for eccentric mean power) and across all maturity groups (concentric mean power). Eccentric mean power explained 61 to 68% in pre- and post-PHV group while concentric power accounted for 37% of the shared variances of maximal velocity in mid-PHV participants. Other kinematic variables (concentric and eccentric time) decreased with increasing maturation. Eccentric time and concentric ground contact times were significantly lower (~-14 to - 21%) in post- compared to pre-PHV participants. Additionally, mid-PHV participants had significantly shorter concentric times (~-9%) compared to pre-PHV participants.

When controlled for years from PHV, no significant differences between all maturity groups in dimensionless vertical and leg stiffness, eccentric and concentric time, and eccentric and concentric power were found. However, significant differences between pre- and mid-PHV compared to post-PHV in eccentric and concentric mean power, were found when age was used as a covariate. From those results it seems that the time of PHV and the changes in maturation (not age) affected many sprint kinetic and kinematic variables.

The increase in height and consequently in weight in developing athletes, also may of resulted in an increase of leg asymmetry and therefore a possible risk for injuries and a potential threat to the athletes' development. With this in mind, chapter nine investigated asymmetries/imbalances in sprint running performance in youth of different maturity status. Averaged over all maturity status, asymmetries in vertical force (19.7%), horizontal force (15.0%), work (19.5%) and power (15.4%) were observed. Positive work was the only variable found to differ significantly ($p < 0.05$) between maturity status, significantly greater asymmetries were found in pre-PHV (26.4%) compared to mid- and post-PHV (~14 to 17%) athletes. As the population in this study was characterised as non-injured, asymmetries of 15-20% appeared typical during a sprint running task in developmental athletes.

Aim 5: Investigate the effect of strength/resisted training method on kinematic and kinetic determinants of sprint running performance in male youth in different maturity status.

In preparation for the training study, we evaluated the acute effects of sled towing using different loads on sprint times in pre- vs. mid-/post-PHV participants. The pre-PHV athletes were significantly slower over 30 m (~33%; $p < 0.05$) than the more mature athletes across all matched relative loads (unloaded, 2.5, 5, 7.5, 10% body mass). Each incremental load (i.e. 2.5% body mass) was found to reduce 30 metre sprint times by ~3% and ~2.3% for the pre- and mid-/post-PHV respectively. The slopes of the pre- and mid-/post-PHV participants regression equations were compared and found to be statistically different ($p = 0.004$), suggesting that athletes of different maturity status respond differentially to the same relative resisted sprint load.

Significantly different responses of pre- vs. mid-/post-PHV athletes to resisted sprint type training were observed in the intervention study. The intervention for a total of 32 children, 18 pre- PHV and 14 mid-/post-PHV, consisted of 16 sessions within 6 weeks of resisted sled towing training with 2-3 sessions per week and 8-10 sprints over 15 to 30 metres with a load of 2.5, 5, 7.5, or 10% body mass for each training session. While pre-PHV participants did not improve 30 metre sprint performance on a non-motorised treadmill after the training, the mid-/post-PHV participants produced significantly better sprint performances i.e. a significant reduction (%change, ES) in sprint time (-5.76, -0.74), dimensionless leg stiffness (-45.0, -2.16) and dimensionless vertical stiffness (-17.4, -0.76) and a significant increase in average velocity (5.99, 0.76), average step rate (5.65, 0.53), average power (6.36, 0.31) and average relative vertical forces (3.45, 1.70). Differences in the percent changes from pre- to post-testing in sprint time, average velocity, peak power, peak horizontal force and relative vertical force were significantly greater in the more mature athletes (mid-/post-PHV participants) and indicated a better response to the training compared to the pre-PHV group. As a conclusion, resisted sprint training would seem a suitable training method in mid-/post-PHV athletes to improve 30 metre sprint performance.

11.2 Delimitations and limitations

Long-term athlete development is a complex and continuous process. Many individual (e.g. genetics, motivation, etc.) as well as environmental factors (equipment, coaching, supportive parents, etc.) will influence the individual's progress and development. We acknowledge that most of the research undertaken in this thesis was cross sectional and not longitudinal in nature and therefore many individual and environmental factors are unaccounted for in our studies. However, as many studies investigating athletes' sprint running development are cross sectional in nature, we followed a similar approach. Furthermore, any benefits associated with resisted type sprint training for youth should be interpreted in context with respect to the individual athlete and his specific sport (sprinter vs. team-sport) and training history. Despite the recruitment of participants with different nationalities and ethnic backgrounds, generalising findings from the series of studies undertaken in this thesis to athletes of other countries/populations and/or ethnic backgrounds should be performed with caution. For example, the magnitude of sprint gains in the Malaysian athletes might not be seen or might be seen to a greater extent in other populations of different nationalities/ethical backgrounds.

Categorising athletes into different maturity groups due to the non-invasive measurement of PHV and uneven distribution of participants in those groups might introduce sources of error. However, we replicated procedures published previously and believe that the small standard deviation in the determination of maturation in each group shows that the measurement of participants maturation were relatively homogeneous (especially in the mid-PHV group).

The methodological procedures of this thesis were for most part only concerned with the development of maximal velocity and therefore only a small part of the athlete's sprint performance. Analysis of other phases of sprint performance, such as acceleration, might have resulted in very different findings.

To measure sprint kinematics and kinetics, a series of in-ground force plates would be the gold standard approach. However, the costs associated with such an approach are usually prohibitive and only a handful of labs in the world have such a budget. The next best approach is the use of a non-motorised treadmill, which has force plates embedded under the belt. The use of the non-motorised treadmill as the principal means of data collection could be interpreted as a limitation of this thesis. Nonetheless, the findings from our thesis should assist athletes and coaches involved with the athlete development process to better understand changes in sprint performance with maturation and possible windows of trainability/accelerated adaption to training.

11.3 Practical applications

The purpose of this thesis was to investigate the effect of maturation on sprint running performance. The main conclusions of this thesis were that maturation influences the development of maximal sprint velocity and most changes in variables contributing to maximal sprint velocity occurred around the time of PHV in male youth. Additionally, a non-motorised treadmill can be used to assess sprint running performance reliably in youth and if needed, the treadmill also provides step-by-step data, which can be used for a more in depth/selective analysis. If customised software solutions are used in connection with the non-motorised treadmill, a 15% body mass step detection threshold should be used whilst analysing sprint running performance. Finally, resisted type sprint training was found more effective in inducing changes in maximal velocity in more mature athletes (mid-/post-PHV participants) compared to their pre-PHV peers.

A major finding from the series of studies in this thesis was that the development of maximal sprint velocity was affected by maturation and not age as proposed in the literature. As a result, changes in sprint development will appear not only due to chronological age, but individually with maturation in the LTAD process, especially around the age of PHV (~14 years of age) in males. Furthermore, most of the changes in sprint mechanics due to maturation were observed in variables associated with horizontal propulsion, like horizontal force, power, or work. It would seem that in order to develop maximal sprint velocity, training that maximises horizontal propulsive ability is desirable, especially in pre- and post-PHV participants.

Prior to changes due to maturation around PHV, training should focus on techniques cues and/or exercise that optimise horizontal force capability. The greatest changes in key variables such as step length, step frequency, horizontal force and power appeared from pre- to mid-PHV participants and given that, a great deal of time should be dedicated to sprint training during these years. Specifically, a training focus on kinematic/technique and co-ordination would benefit this group as it was seen that at years of PHV predictors of maximal velocity changed from horizontal force and power to vertical force, step length and contact time.

Whilst there seems to be no doubt that technique training needs to continue throughout all phases of maturation and certainly when the rate of PHV changes the most (i.e. around mid-PHV) i.e. to combat adolescent awkwardness, the training of post-PHV participants should focus on exercises targeting kinematic (contact time) and kinetic (horizontal force and power) variables.

Changes in variables associated with SSC at the same maturity stage reinforce previous statements. The ability to absorb power improves around the time of PHV and therefore the ability for increased power production is refined after maturation. Training that targets slow eccentric strengthening concentrating on technique would seem appropriate in pre-PHV state, mid- and post-PHV athletes would most likely benefit from faster and more complex eccentric exercises that concentrate on minimising contact time.

The resisted type sprint training used in this thesis resulted in sprint running improvements in the mid-/post-PHV participants, whilst the training had minimal influence on the sprint performance of the pre-PHV participants. It would seem that maturation and changes associated with maturation affect readiness to utilise resisted type sprint training such as sled towing.

Finally the loading parameters used in this thesis might guide the programming of athletes in mid-/post-PHV maturation status utilising resisted sled towing training. The mid-/post-PHV athletes participated on average in 14 training sessions with 2-3 sessions per week over six weeks. Sprints over 15 to 30 m with a load of 2.5, 5, 7.5, or 10% body mass ensured progression throughout the training intervention and were found to significantly improve sprint performance.

11.4 Future research

Future research could possibly target four different areas of the sprint development in the LTAD process. First, while this thesis focused on maximal velocity, a logical extension of the present thesis would be the investigation of kinetic and kinematic variables in different phases of sprinting, e.g. the acceleration phase, with regard to maturation. Such investigation would further disentangle the effect of maturation on sprint performance and would provide foundations for more specific programming for different sprint phases.

The second area of research focus could involve investigating the effects of different training methods. From the review of literature, it was observed that other training methods (than resisted type sprint training) improved maximal velocity and/or different phases of sprint performance with regards to youth of different maturity status. For example, training forms that are thought to influence the neuromuscular system such as plyometrics have been shown effective in mid- and post-PHV groups, however, there still seems to be an absence of the training effects for pre-PHV participants.

The third area for future research could focus on the dose-response relationship with regards to all specific and non-specific training forms, and their influence on all sprint phases in developmental athletes of different maturity status. While the training study in this thesis demonstrated the efficacy of resisted type sprint training in mid-/post-PHV participants, it seems possible that pre-PHV participants could have needed more training sessions to improve sprint performances. Furthermore, specific and non-specific training should focus on variables directly related with variables shown crucial in this thesis. That is, exercises thought to influence horizontal vs. vertical direction could be of further interest in especially mid-PHV participants. In general, research in the area of dose-response relationship, would benefit coaches and practitioners by providing important scientific knowledge about the loading parameters needed to induce changes in youth of different maturity status. In addition, such information could provide specific knowledge about the load imposed onto athletes of different maturity status in the LTAD process in order to avoid overtraining and injuries.

The final focus of future research could be on the participants themselves. The participants in the series of studies in this thesis were categorised as athletic. A greater pool of “talented” youth of different maturity status might provide normative data/benchmarks for those populations in different phases of sprint performance in the LTAD process. Additionally, it seems plausible to reproduce the studies in athletic youth of different maturity status with different nationality/ethnic backgrounds.

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Appendices

Appendix 1: Ethics approvals

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:	John Cronin
From:	**Madeline Banda** Executive Secretary, AUTEC
Date:	22 December 2009
Subject:	Ethics Application Number 09/291 **Reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children.**

Dear John

I am pleased to advise that the Auckland University of Technology Ethics Committee (AUTEC) approved your ethics application at their meeting on 14 December 2009, subject to the following conditions:

1. Provision of a revised response to section B.7 of the application, answering the question asked in relation to the research under consideration. The applicant and researcher are referred to AUTEC's prompts in the Frequently Asked Questions section of the Ethics Knowledge Base (accessible online via http://www.aut.ac.nz/research/research-ethics) for assistance;
2. Provision of an Information Sheet in appropriate language and an Assent Form for participants who are legal minors;
3. Provision of an Information Sheet and a Consent Form for the parents or legal guardians of those participants who are legal minors. This Information Sheet also needs to give parents or legal guardians the option of being present at the tests, should they wish to do so.

AUTEC recommends that the Information Sheets contain pictures of what will be involved to assist clarity. AUTEC noted that the qualifications of the applicant were not included in the responses to part A of the application and advises that these are to be included in future ethics applications.

I request that you provide the Ethics Coordinator with a written response to the points raised in these conditions at your earliest convenience, indicating either how you have satisfied these points or proposing an alternative approach. AUTEC also requires written evidence of any altered documents, such as Information Sheets, surveys etc. Once this response and its supporting written evidence has been received and confirmed as satisfying the Committee's points, you will be notified of the full approval of your ethics application.

When approval has been given subject to conditions, full approval is not effective until *all* the concerns expressed in the conditions have been met to the satisfaction of the Committee. Data collection may not commence until full approval has been confirmed. Should these conditions not be satisfactorily met within six months, your application may be closed and you will need to submit a new application should you wish to continue with this research project.

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

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Michael Rumpf mrumpf@aut.ac.nz

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:	John Cronin
From:	**Dr Rosemary Godbold** Executive Secretary, AUTEC
Date:	3 August 2011
Subject:	Ethics Application Number 11/149 **The effect of strength/resisted training methods on sprinting and jumping performance in youth.**

Dear John

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 27 June 2011 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 22 August 2011.

Your ethics application is approved for a period of three years until 3 August 2014.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 3 August 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 3 August 2014 or on completion of the project, whichever comes sooner;

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

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

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

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

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Michael Rumpf mrumpf@aut.ac.nz

Appendix 2: Participation information sheet

Participant Information Sheet

AUT UNIVERSITY

Date Information Sheet Produced:

25 November 2009

Project Title

Reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children

An Invitation

I, Michael Rumpf, am a Doctoral candidate at the AUT University in Auckland, as well as the head coach of speed training at the Millennium Institute of Sport and Health (MISH).

I would like to invite you to participate in a project, studying speed in youth. You can choose either to participate or not participate in the study and your choice will not affect your training. If you start the study please understand that you may stop at any time without any problems.

What is the purpose of this study?

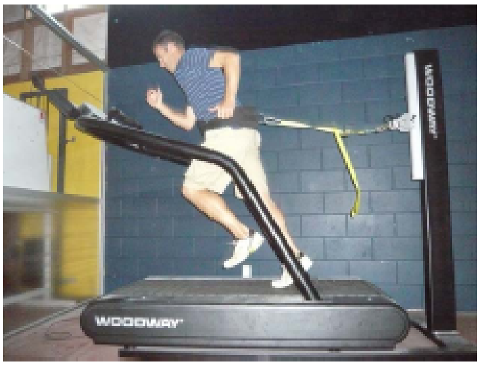
The purpose of this study is to examine how some variables (e.g. stride length) measured on a non-motorised treadmill are important in determining speed in young athletes.

How was I chosen for this study?

You are a young athlete that is active and playing sport.

What will happen in this research?

You will be asked to run on a treadmill (see figure) four different times. The first session will be a practice session, consisting of standing, walking and running at a speed chosen by you. This will also be used as a warm-up phase (~5 minutes) and some stretching will follow. You will then perform 3 x 30 metre warm-up sprints on the treadmill. After that we will start measuring how fast you can sprint over 30 metres for three times. After each sprint you will have time (about 3 minutes) to rest. Your highest speed will be found and you will perform another three sprints at 80%, then 60%, and then 40% of your highest speed. There will be 3 minutes of rest between each sprint. The exact same procedures will be replicated on testing days 2, 3 and 4.



What are the risks?

Muscle soreness from sprinting on the treadmill will differ very little to regular sprinting. The main soreness you may have during some of the tests is a mild soreness sensation in your legs along with some heavy breathing. These are normal and happen with most forms of hard exercise. Any soreness or hard breathing should end quite quickly during the rest period after each sprint.

How will the risks be alleviated?

We will ask you to practice standing, walking, running and sprinting on the treadmill prior to us collecting any data on you running, so you feel at ease with the test. We will also ask you to warm-up and stretch properly before sprinting. You should also keep warm and drink fluids throughout the testing session.

Immediately after each run, you will be asked to step off the treadmill and keep on walking on the ground, which will help you recover. Please let the researcher know if you feel that you need more time to recover between tests. Finally, please tell the researcher, if you have a current injury or have had an injury within the last four months that might affect you sprinting on the treadmill.

What are the benefits?

By you being involved in this study, you are helping us understand what makes young athletes run fast. Also if you are interested we can give you a summary of your results.

What happens if I am injured?

In the unlikely event of an injury as a result of you running in this study you will receive medical help that will depend on the nature of your injury e.g. see a doctor.

How will my privacy be protected?

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

What are the costs of being in this study?

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

How do I decide to be involved in the study?

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

Will I receive feedback on the results of this study?

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

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

If you have any concerns regarding this study you should ask your parents to contact the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

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

Whom do I contact for further information about this research?

Please contact the student researcher, Michael Rumpf, mrumpf@aut.ac.nz, mobile 0226 008 226.

Approved by the Auckland University of Technology Ethics Committee on: 08.02.2010, AUTEC Reference number 09/291.

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced / *Tarikh Borang Dikeluarkan:*

15th of July 2011/ *15 Julai 2011*

Project Title / *Tajuk Projek*

The effect of strength/resisted training methods on sprinting and jumping performance in boys
Kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan remaja lelaki

An Invitation /*Jemputan*

I, Michael Rumpf, am a Doctoral candidate at the AUT University in Auckland (New Zealand), as well as the head coach of speed training for the long term athlete development (LTAD) program at the Millennium Institute of Sport and Health (MISH) and the Football Fitness Manager for New Zealand Football (NZF).

Saya, Michael Rumpf, calon Doktor Falsafah daripada Universiti AUT di Auckland (New Zealand), juga merupakan ketua jurulatih pecutan bagi program pembangunan atlit jangka masa panjang (LTAD) di Millennium Institute of Sport and Health (MISH) dan Pengurus Jurulatih Kecergasan Bolasepak bagi pasukan bolasepak New Zealand (NZF).

I would like to invite your child to participate in a research studying the effects of strength/resisted training on sprint and jumping performance in boys. His participation is entirely voluntary and whether or not he chooses to participate will neither advantage nor disadvantage him in relation to his training. Please understand that your son may withdraw at any time without any adverse consequences.

Saya dengan ini ingin menjemput penyertaan anak Tuan/Puan dalam penyelidikan saya yang bertajuk seperti yang di nyatakan di atas. Penyertaan anak Tuan/Puan adalah atas dasar sukarela, dan samada beliau atau Tuan/Puan memilih untuk menyertai atau tidak, tiada sebarang faedah atau pengurangan faedah yang akan dinikmati berhubung kait dengan latihan anak Tuan/Puan. Sukacita diingatkan juga bahawa anak Tuan/Puan boleh menarik diri daripada menyertai pada bila-bila masa tanpa sebarang akibat.

What is the purpose of this research? / *Apakah tujuan kajian ini?*

The primary purpose of this study is to investigate the effect of strength/resisted training method on sprinting and jumping performance young athletes.

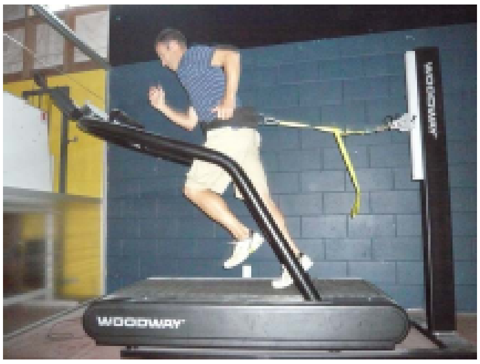
Tujuan utama kajian ini adalah untuk menyelidiki kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan atlit kanak-kanak dan remaja.

How was I chosen for this invitation? / *Bagaimana saya terpilih untuk jemputan ini?*

You are young athlete that is regularly physically active and currently involved in training monitored directly/indirectly by Physical Conditioning coach of National Sports Institute of Malaysia (ISN).

Anda adalah antara atlit remaja/kanak-kanak yang pada masa ini aktif secara fizikal dan mengikuti latihan secara langsung/tidak langsung dengan jurulatih Suaian Fizikal Insititut Sukan Negara Malaysia (ISN)

What will happen in this research? / *Apa akan berlaku dalam penyelidikan ini?*



There are three parts in this study; two testing sessions and a 10-week training period. During the two testing sessions we would like to assess you on a non-motorised treadmill (see figure), overground sprinting and jumping. The first session will be a practice session, where you will walk and run at a speed chosen by you. This will also be used as a warm-up phase (~5 minutes) and some stretching will follow. You will then perform 3 x 30 metre warm-up sprints on the treadmill. After that we will start measuring how fast you can sprint over 30 meters for three times. After each sprint you will have time (about 3 minutes) to rest. You will then sprint for 30 meters overground twice. The following tests will consist of 3 vertical jumps and 3 horizontal jumps. There will be again 3 minutes of rest between each sprint and each set of jumps. The 10-week strength/resisted training period will consist of body weight strength exercises and resisted sprint training.

Penyelidikan ini akan mengandungi dua sesi latihan (ujian awal dan akhir) di mana di antara kedua-dua sesi ujian tersebut atlit terbabit akan mengikuti 10-minggu latihan kekuatan/rintangan untuk pecutan. Sewaktu sesi ujian awal dan akhir, anda akan di uji di atas "Woodway non-motorised treadmill" (gambar), larian pecutan atas tanah dan lompatan. Sebelum ujian di jalankan, anda akan terlebih dahulu di beri peluang menyesuaikan diri dengan alatan ujian dalam sesi penyesuaian yang akan termasuk berdiri, berjalan dan berlari dengan kelajuan pilihan sendiri di atas "treadmill" tersebut (juga di anggap sebagai 'warm-up' ~5 minit). Aktiviti regangan menyusul kemudiannya. Selepas sesi regangan anda akan melakukan beberapa siri pecutan di atas 'treadmill' tersebut, contohnya 3 x 30 m. Selepas itu anda akan memecut sejauh 30 meter sebanyak tiga kali dengan waktu rehat secukupnya kan di berikan di antara sela masa rehat pecutan tersebut. Anda kemudiannya akan melakukan dua kali pecutan 30 m atas trek, 3 kali lompatan ke atas dan 3 kali lompatan hadapan. Anda sekali lagi akan di beri waktu rehat yang secukupnya selepas setiap aktiviti tersebut. Latihan kekuatan/rintangan 10-minggu akan mengandungi senaman latihan bebanan menggunakan berat badan sendiri dan pecutan berintangan.

What are the risks? *Apakah risiko terlibat?*

Muscle soreness from sprinting on the treadmill or strength exercises will differ little to your regular training. The main soreness you may have during some of the tests and the training is a mild soreness sensation in your legs along with some heavy breathing. These are normal and happen with most forms of hard exercise. Any soreness or hard breathing should end quite quickly during the rest period after each sprint during testing and training.

Ketidakselesaan dan risiko yang mungkin bagi ujian yang di jalankan adalah hampir sama dengan ketidakselesaan dan risiko yang sewaktu melakukan larian pecutan dan lompatan biasa atas trek /tanah. Ketidakselesaan utama anda mungkin alami adalah kelesuan ringan otot kaki dan mengah sementara yang biasa di alami akibat larian. Respon sebegini adalah biasa bagi aktiviti fizikal terutamnyanya membabitkan sedikit pecutan dan lompatan. Bagi latihan, darjah kesukaran dan kesan yang di alami adalah bergantung kepada tahap kecergasan terkini anda, dan toleransi terhadap pecutan dan lompatan. Semua yang di sebutkan ini kebiasaannya akan hilang kesannya sewaktu sesi rehat selepas setiap aktiviti tersebut tamat di jalankan.

How will the risks be alleviated? / *Bagaimana risiko diatasi?*

We will ask you to practice standing, walking, running and sprinting on the treadmill prior to us collecting any data on you running, so you feel at ease with the test. We will also ask you to warm-up and stretch properly before sprinting on the treadmill. There will also be a regular warm up period within each training session. You should also keep warm and drink fluids throughout the testing sessions and training.

Anda akan diminta melakukan latihan berdiri, berjalan, berlari, dan memecut di atas 'treadmill' sebelum kutipan data sebenar dilakukan sewaktu anda berlari. Anda juga akan diminta melakukan aktiviti memanaskan badan dan regangan sebaiknya sebelum melakukan pecutan di atas 'treadmill'. Aktiviti *rutin memanaskan badan juga akan diteruskan dalam sesi latihan. Anda sepatutnya mengekalkan suhu badan sepatutnya dan meminum air secukupnya sepanjang sesi ujian dan latihan.*

Immediately after each run, you will be asked to keep on walking on the ground, which will help you recover. Please let the researcher know if you feel that you need more time to recover between tests. The same procedures will also apply for the training sessions. Walking between exercises/sprints will assist recovery and stretching will conclude each training day to further reduce discomforts or risk of injury. Finally, please tell the researcher, if you have a current injury or have had an injury within the last four months that might affect you sprinting or jumping.

Setiap kali selepas larian, anda akan di minta berjalan di atas lantai, yang mana akan membantu pemulihan anda. Sila maklumkan kepada penyelidik sekiranya anda perlu masa tambahanh untuk pemulihan antara setiap ujian. Prosedur sama juga akan digunakan sewaktu latihan. Berjalan di antara senaman/pecutan akan membantu pemulihan dan regangan akan dilakukan pada kahir latihan atau ujian untuk mengurangkan ketidakselesaan atau risiko kecederaan. Akhir sekali, sila maklumkan kepada penyelidik, sekiranya anda mengalami sebarang kecederaan pada masa ini atau sekurang-kurangnya 4 bulan sebelum ini yang mungkin member kesan kepada pecutan atau lompatan anda.

What are the benefits? / *Apakah faedah?*

By you being involved in this study, you are helping us understand what makes young athletes run fast. Also if you are interested we can give you a summary of your results.

Dengan terlibat dalam penyelidikan ini, anda membantu kami untuk memahami apa yang membuatkan atlit remaja berlari lebih pantas. Juga ada akan berminat dengan keputusan ujian anda yang akan kami berikan nanti.

What happens if I am injured? / *Apa akan terjadi sekiranya saya tercedera?*

In the unlikely event of an injury as a result of you running or jumping in this study you will receive medical help from the doctors at the National Sports Institute Malaysia (ISN) and it will not cost you anything.

Dalam keadaan tidak disangka sekiranya berlaku kecederaan fizikal atas pembabitan anda dalam penyelidikan ini, rehabilitasi dan kompensasi untuk kecederaan akibat kemalangan akan tersedia sebagaimana yang diperuntukkan oleh ISN untuk atlit-atlit yang terbabit dalam program anjuran / di kemudahan mereka.

How will my privacy be protected? / *Bagaimana kerahsiaan peribadi saya dilindungi?*

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

Dapatan ujian peribadi anda akan disimpan dalam kerahsiaan di mana hanya dua orang sahaja akan melihatnya, dan dapatan kajian anda kemudiannya akan diletakkan bersama data atlit lain dan dianalisa secara kelompok.

What are the costs of being in this study?

There are no costs of being in this study apart from your time for testing. We will have two testing sessions which will be about 1.5 hours in length each and you will therefore have to spend a total of additional 3 hours at the ISN for testing. Your parents can be present at your testing days, if you wish them to be there. The training will be co-operated into your regular training, therefore you will not have to spend more time in training than usual.

Tiada kos terlibat kecuali keperluan masa anda untuk menjalani ujian terbabit. Kita akan mempunyai dua sesi ujian yang akan mengambil masa lebih kurang 1.5 jam setiap satu dan untuk itu anak anda perlu meluangkan masa keseluruhannya lebih kurang 3 jam di ISN untuk setiap kali ujian. Penjaga anda boleh hadir pada masa ujian sekiranya mahu. Latihan terlibat akan digabungkan bersama ke dalam sesi latihan biasa anda, dengan itu tiada masa tambahan akan terlibat.

How do I decide to be involved in the study? / *Bagaimana saya memutuskan untuk terlibat?*

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

Selepas anda membaca borang ini, anda akan mempunyai masa untuk berbincang dengan ibubapa penjaga anda dan bertanyakan penyelidik bagi sebarang kemusykilan yang timbul. Selepas semua persoalan anda terjawap, anda perlu memutuskan samada untuk terlibat atau tidak. Sekiranya anda memutuskan untuk terlibat dalam penyelidikan ini, anda akan mengisi dan menandatangani borang Assent Form sebelum terlibat dengan sebarang ujian, dan akan menghantar borang tersebut kepada Michael rumpf bersama dengan borang Parent or Guardian Form. Sila ambil maklum bahawa anda tidak akan dibenarkan terlibat dalam penyelidikan ini sekiranya anda atau ibubapa penjaga anda tidak mengisi dan memulangkan borang-borang terbabit. Sekiranya anda tidak berminat untuk terlibat, mohon juga maklumkan kepada penyelidik.

Will I receive feedback on the results of this study? / *Adakah saya akan menerima maklumbalas berkaitan dapatan kajian ini?*

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

Ya, anda akan menerima ringkasan dapatan kajian apabila semua maklumat telah sedia untuk diedarkan Sila tandakan di dalam kotak berkaitan di dalam 'Consent Form' sekiranya anda inginkan maklumat ini.

What do I do if I have concerns about this study? *Apa yang saya patut buat sekiranya ada keraguan berhubung kajian ini?*

If you have any concerns regarding this study you should ask your parents to contact the Project Supervisor, Dr John Cronin, john.cronin@aut.ac.nz, telephone: 09 921 9999, extension 7523.

Sebarang keraguan berkaitan projek penyelidikan ini boleh berhubung terus dengan Penyelia Projek, Dr. John Cronin, john.cronin@aut.ac.nz, telefon: 09 921 9999, sambungan 7523.

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

Keraguan berkaitan cara penyelidikan ini dijalankan boleh berhubung terus dengan Setiausaha Eksekutif, AUTEC, Madaline Banda, Madeline.banda@aut.ac.nz, telefon: 09 921 9999, sambungan 8044.

Whom do I contact for further information about this research? / *Siapa patut saya hubungi berkaitan penyelidikan ini?*

Please contact the student researcher, Michael Rumpf, mrumpf@aut.ac.nz, mobile +64-226-008-226 or Dr. Nur Ikhwan Mohamad, nur.ikhwan@fsski.upsi.edu.my

Sila berhubung terus dengan penyelidik, Michael Rumpf, mrumpf@aut.ac.nz, telefon bimbit 0226 008 226 atau Dr. Nur Ikhwan Mohamad, nur.ikhwan@fsski.upsi.edu.my

Approved by the Auckland University of Technology Ethics Committee on 3/8/2011: AUTEC Reference number: 11/149.
Diluluskan oleh Jawatankuasa Etika Auckland University of Technology pada: AUTEC Reference number: 11/149.

Appendix 3: Parents information sheet

Parents Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced:

25 November 2009

Project Title

Reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children

An Invitation

I, Michael Rumpf, am a Doctoral candidate at the AUT University in Auckland, as well as the head coach of speed training for the long term athlete development (LTAD) program at the Millennium Institute of Sport and Health (MISH).

I would like to invite your child to participate in a research studying the determinants of speed in youth. His/her participation is entirely voluntary and whether or not he/she chooses to participate will neither advantage nor disadvantage him/her in relation to his/her training. Please understand that your son/daughter may withdraw at any time without any adverse consequences.

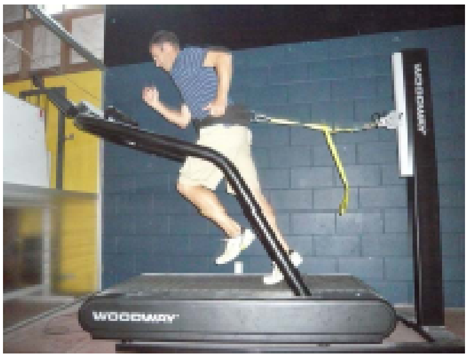
What is the purpose of this research?

The purpose of this project is to examine the reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children.

How was my child chosen for this invitation?

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

What will happen in this research?



Your son/daughter will be assessed on four occasions on a Woodway non-motorised treadmill (see figure). He/she will receive a familiarization session on the treadmill, consisting of standing, walking and running at a self chosen speed, which will also be taken as a warm-up phase (~5 minutes). A standardised stretching protocol will follow. Your child will then perform a series of warm-up sprints on the treadmill i.e. 3 x 30 m. After that he/she will sprint at maximal velocity (Vmax) over 30 m, three times with enough time to recover completey (~3 minutes) between trials. The average of the max speed obtained during the three runs will be used as his/he 100% Vmax for the following procedures. Three trials at 80%, 60%, and 40% Vmax will be performed for six seconds after your child has accelerated to his/her target speed. There will be 3 minutes of rest between each trial. For the reliability analysis the exact same procedures will be replicated on testing occasions 2 and 3. Variables found reliable will be assessed on one additional testing day.

What are the discomforts and risks?

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

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

How will these discomforts and risks be alleviated?

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

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

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

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

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

What are the benefits?

By participating in this study, your child provides us with data, which helps to develop suitable tests that provide information about the Woodway treadmill in using children and sprinting performance of active children. He/she will be able to compare his/her results to the groups of interest and gain some insight into the relevance of his/her test results to sprinting performance. A summary of your child's results and the study will be available to you and your son/daughter on completion of the project.

What compensation is available for injury or negligence?

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

How will my child's privacy be protected?

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

What are the costs of participating in this research?

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

What opportunity does my child have to consider this invitation?

After he/she has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion. The initial familiarization day of the testing sessions is scheduled to commence February 2010, to ask any further questions and to receive feedback about your technique. The second and third days are scheduled to occur mid to end February 2010 (you will be advised of your actual testing dates with at least two weeks advance notice). The fourth testing day will occur at the end of February.

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

How do my child agree to participate in this research?

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

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

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

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

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

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

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

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

Please contact the student researcher, Michael Rumpf, mrumpf@aut.ac.nz, mobile 0226 008 226.

Student Researcher Contact Details:

Michael Rumpf, mrumpf@aut.ac.nz, mobile 0226 008 226

Project Supervisor Contact Details:

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

Approved by the Auckland University of Technology Ethics Committee on: 08.02.2010, AUTEC Reference number 09/291.

Parents Information Sheet

Date Information Sheet Produced / *Tarikh Kertas Makluman Di keluarkan:*

30th of May 2011 / *30th Mei 2011*

Project Title / *Tajuk Penyelidikan*

The effect of strength/resisted training methods on sprinting and jumping performance in boys.
Kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan remaja lelaki

An Invitation /*Jemputan*

I, Michael Rumpf, am a Doctoral candidate at the AUT University in Auckland (New Zealand), as well as the head coach of speed training for the long term athlete development (LTAD) program at the Millennium Institute of Sport and Health (MISH) and the Football Fitness Manager for New Zealand Football (NZF).

Saya, Michael Rumpf, calon Doktor Falsafah daripada Universiti AUT di Auckland (New Zealand), juga merupakan ketua jurulatih pecutan bagi program pembangunan atlit jangka masa panjang (LTAD) di Millennium Institute of Sport and Health (MISH) dan Pengurus Jurulatih Kecergasan Bolasepak bagi pasukan bolasepak New Zealand (NZF).

I would like to invite your child to participate in a research studying the effects of strength/resisted training on sprint and jumping performance in boys. His participation is entirely voluntary and whether or not he chooses to participate will neither advantage nor disadvantage him in relation to his training. Please understand that your son may withdraw at any time without any adverse consequences.

Saya dengan ini ingin menjemput penyertaan anak Tuan/Puan dalam penyelidikan saya yang bertajuk seperti yang di nyatakan di atas. Penyertaan anak Tuan/Puan adalah atas dasar sukarela, dan samada beliau atau Tuan/Puan memilih untuk menyertai atau tidak, tiada sebarang faedah atau pengurangan faedah yang akan dinikmati berhubung kait dengan latihan anak Tuan/Puan. Sukacita diingatkan juga bahawa anak Tuan/Puan boleh menarik diri daripada menyertai pada bila-bila masa tanpa sebarang akibat.

What is the purpose of this research? / *Apakah tujuan kajian ini?*

The primary purpose of this study is to investigate the effect of strength/resisted training method on sprinting and jumping performance young athletes.

Tujuan utama kajian ini adalah untuk menyelidiki kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan atlit kanak-kanak dan remaja.

How was my child chosen for this invitation? / *Bagaimana anak saya terpilih untuk jemputan ini?*

Your child is a young athlete that is regularly physically active and currently involved in training monitored directly/indirectly by Physical Conditioning coach of National Sports Institute of Malaysia (ISN).

Anak anda adalah antara atlit remaja/kanak-kanak yang pada masa ini aktif secara fizikal dan mengikuti latihan secara langsung/tidak langsung dengan jurulatih Suaian Fizikal Institut Sukan Negara Malaysia (ISN)

What will happen in this research? / *Apa akan berlaku dalam penyelidikan ini?*

The research consists of two testing sessions (pre- and post-testing) and a 10-week strength/resisted sprint training period. During the pre- and post-testing your son will be assessed on a Woodway non-motorised treadmill (see figure), overground sprinting and jumping. Before we will capture data, he will receive a familiarization session on the treadmill, consisting of standing, walking and running at a self chosen speed, which will also be taken as a warm-up phase (~5 minutes). A standardised stretching protocol will follow. Your child will then perform a series of warm-up sprints on the treadmill i.e. 3 x 30 m. After that he will sprint for 30 meters for three times with enough time to recover completey (~3 minutes) between trials. Afterwards he will then perform two 30 m sprints over ground, followed by 3 vertical jumps and 3 horizontal jumps. Your son will again be able to recover completely after each sprint and/or jump. The 10-week strength/resisted training period will consist of body weight strength exercises and resisted sprint training.

Penyelidikan ini akan mengandungi dua sesi latihan (ujian awal dan akhir) di mana di antara kedua-dua sesi ujian tersebut atlit terbabit akan mengikuti 10-minggu latihan kekuatan/rintangan untuk pecutan. Sewaktu sesi ujian awal dan akhir, anak Tuan/Puan akan di uji di atas "Woodway non-motorised treadmill" (gambar), larian pecutan atas tanah dan lompatan. Sebelum ujian di jalankan, anak Tuan/Puan akan terlebih dahulu di beri peluang menyesuaikan diri dengan alatan ujian dalam sesi penyesuaian yang akan termasuk berdiri, berjalan dan berlari dengan kelajuan pilihan sendiri di atas "treadmill" tersebut (juga di anggap sebagai 'warm-up' ~5 minit). Aktiviti regangan menyusul kemudiannya. Selepas sesi regangan anak Tuan/Puan akan melakukan beberapa siri pecutan di atas 'treadmill' tersebut, contohnya 3 x 30 m. Selepas itu beliau akan memecut sejauh 30 meter sebanyak tiga kali dengan waktu rehat secukupnya kan di berikan di antara sela masa rehat pecutan tersebut. Beliau kemudiannya akan melakukan dua kali pecutan 30 m atas trek, 3 kali lompatan ke atas dan 3 kali lompatan hadapan. Anak Tuan/Puan sekali lagi akan di beri waktu rehat yang secukupnya selepas setiap aktiviti tersebut. Latihan kekuatan/rintangan 10-minggu akan mengandungi senaman latihan bebanan menggunakan berat badan sendiri dan pecutan berintangan.

What are the discomforts and risks? / *Apakah ketidakselesaan dan risiko terlibat?*

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

Ketidakselesaan dan risiko yang mungkin bagi ujian yang di jalankan adalah hampir sama dengan ketidakselesaan dan risiko yang sewaktu melakukan larian pecutan dan lompatan biasa atas trek /tanah. Ketidakselesaan utama anak Tuan/Puan mungkin alami adalah kelesuan ringan otot kaki dan mengah sementara yang biasa di alami akibat larian. Respon sebegini adalah biasa bagi aktiviti fizikal terutamnyanya membabitkan sedikit pecutan dan lompatan. Bagi latihan, darjah kesukaran dan kesan yang di alami adalah bergantung kepada tahap kecergasan terkini mereka, dan toleransi terhadap pecutan dan lompatan. Semua yang di sebutkan ini kebiasaannya akan hilang kesannya sewaktu sesi rehat selepas setiap aktiviti tersebut tamat di jalankan.

The other possible discomfort is delayed onset of muscle soreness (DOMS) the following or subsequent two days after testing/training. However, your child is less likely to get DOMS after using the non-motorized treadmill as your son will have enough time to recover in between trials and after each training day. Any muscle soreness should dissipate within 3 to 5 days. A stretching period at the end of each training session will further reduce discomforts, DOMS and any other possible muscular injury.

Satu lagi kemungkinan adalah anak Tuan/Puan akan mengalami apa yang pakar sualan fizikal istilahkan sebagai 'delayed onset muscle soreness' (DOMS), yang biasanya di alami sehari atau dua selepas latihan. Walaubagaimanapun, anak Tuan/Puan berkemungkinan tidak akan mengalami DOMS selepas *larian atas 'treadmill' dan selepas latihan harian kerana masa rehat dan aktiviti regangan secukupnya akan diberikan. Sebarang kelesuan otot yang di alami kebiasaannya akan hilang dalam 3 hingga 5 hari. Aktiviti regangan pada setiap kali tamat latihan akan mengurangkan risiko DOMS dan mengurangkan ketidakselesaan dan mengelakkan kecederaan selepas latihan.*

How will these discomforts and risks be alleviated? *I Bagaimana ketidakselesaan dan risiko ini di atasi?*

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

Anak anda akan diberi peluang untuk menjalani sesi penyesuaian terlebih dahulu bagi mengatasi ketidakselesaan dan risiko yang di sebutkan di atas.

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

Untuk mengurangkan ketidakselesaan dan risiko daripada ujian dan latihan, anak anda akan di minta bersedia secara fizikal sebelum setiap ujian dan latihan dengan melakukan aktiviti memanaskan badan. Ketidakselesaan dan risiko akan juga berkurangan dengan atlit terbabit mengekalkan suhu bdan yang bersesuain untuk aktiviti fizikal dan minum air secukupnya sepanjang sesi ujian dan latihan.

Immediately after each test, he will be asked to walk on the ground to keep blood circulating and to assist recovery – light walking is better than standing still or lying down. If your child needs more time to prepare or recover between tests, he should notify the researcher, as we are interested in measuring his best performance. Similar procedures also apply for the training sessions. Walking between exercises/sprints will assist recovery and stretching will conclude each training day to further reduce discomforts or risk of injury.

Setiap kali selepas ujian, anak anda akan segera di minta berjalan sekitar bilik ujian untuk menggalakkan pengaliran darah dan membantu pemulihan – berjalan perlahan adalah lebih baik daripada berdiri tegak atau berbaring. Sekiranya anak anda memerlukan lebih masa untuk bersedia atau pulih kepada keadadan biasa antara setiap ujian, beliau diminta memaklumkan kepada penyelidik, ini kerana kami ingin mengukur prestasi terbaik beliau dan bukannya prestasi sewaktu belum pulih sepenuhnya. Prosedur sama akan digunakan sewaktu latihan. Berjalan anatar senaman/pecutan akan membantu pemulihan dan aktiviti regangan akan mnjadi penutup setiap sesi latihan untuk mengurangkan ketidakselesaan atau kecederaan.

If your child does not feel able to complete the tasks requested, he should notify the researcher immediately and the testing will be terminated as well as the training session for that day.

Sekiranya anak anda merasakan tidak mampun menamatkan aktiviti yang diberikan, beliau sepatutnya memaklumkan kepada penyelidik secepat mungkin, di mana ujian dan latihan akan diberhentikan serta merta untuk sesi tersebut.

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

Akhir sekali, anak anda sepatutnya memaklumkan kepada penyelidik, sekiranya beliau mempunyai kecederaan atau pernah mempunyai kecederaan dalam tempoh 4 bulan sebelumnya yang mungkin mempengaruhi prestasinya atau mungkin akan menjadi lebih teruk sekiranya mengikuti ujian/latihan dalam penyelidikan ini. Sekiranya ketidakselesaan dan risiko ini wujud sewaktu ujian atau latihan, pihak penyelidik akan mencadangkan anak anda menarik diri daripada ujian tersebut.

What are the benefits? *Apakah faedah penyertaan?*

By participating in this study, your child provides us with data, which helps us prepare young athletes more efficiently and potentially reduce injuries. A summary of your child's results and the study will be available to you and your son on completion of the project.

Dengan menyertai penyelidikan ini, anak anda akan membantu memberikan kami data, yang akan menyediakan atlit remaja dan kanak-kanak dengan lebih baik dan memngurangkan risiko kecederaan atlit remaja dan kanak-kanak dalam pembabitan latihan sukan untuk prestasi. Ringkasan keputusan ujian-ujian yang dijalankan boleh diperolehi untuk rujukan pihak Tuan/Puan daripada penyelidik selepas projek ini tamat.

What compensation is available for injury or negligence? / *Apakah bentuk kompensasi yang disediakan untuk kecederaan dan kecualan?*

In the unlikely event of a physical injury as a result of your child's participation in this study, rehabilitation and compensation for injury by accident will be available from the ISN free of charge in accordance with what have normally been provided for athletes and anyone who involved in any training or program by ISN at their facilities

Dalam keadaan tidak disangka sekiranya berlaku kecederaan fizikal atas pembabitan anak anda dalam penyelidikan ini, rehabilitasi dan kompensasi untuk kecederaan akibat kemalangan akan tersedia sebagaimana yang diperuntukkan oleh ISN untuk atlit-atlit yang trbabit dalam program anjuran / di kemudahan mereka.

How will my child's privacy be protected? / *Bagaimana kerahsian peribadi anak saya dilindungi?*

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

Identiti dan keputusan ujian setiap peserta adalah dirahsiakan. Hanya penyelidik (Michael Rumpf) dan penyelia utama beliau (Prof. John Cronin) akan menganalisa data terbabit. Data keputusan ujian akan hanya mengenalpasti peserta mengikut kod nama tertentu, dan kebiasaannya hasil dapatan semua peserta digabungkan bersama dan dikeluarkan dalam bentuk purata keseluruhan sekiranya ditunjukkan kepada umum.

What are the costs of participating in this research? / *Apakah kos pembabitan dalam penyelidikan ini?*

There are no costs of being in this study apart from you and your child's time to be available for testing. We will have two testing sessions which will be about 1.5 hours in length each and your child will therefore have to spend a total of additional 3 hours at the ISN for testing. You can be present at the testing if you wish. The training will be co-operated into your regular training schedule, therefore there will not be any additional time required.

Tiada kos terlibat kecuali keperluan masa anda dan anak anda untuk menjalani ujian terbabit. Kita akan mempunyai dua sesi ujian yang akan mengambil masa lebih kurang 1.5 jam setiap satu dan untuk itu anak anda perlu meluangkan masa keseluruhannya lebih kurang 3 jam di ISN untuk setiap kali ujian. Anda boleh hadir pada masa ujian sekiranya mahu. Latihan terlibat akan digabungkan bersama ke dalam sesi latihan biasa anak anda, dengan itu tiada masa tambahan akan terlibat.

What opportunity does my child have to consider this invitation? / *Apakah peluang yang anak saya ada dalam mempertimbangkan jemputan ini?*

After he has read through this form, you and your child will have plenty of opportunity to ask any questions you would like about the study up to the first testing occasion.

Selepas beliau dan anda membaca / diberi taklimat berkaitan boring ini, anda dan anak anda akan mempunyai banyak peluang untuk bertanya berkaitan penyelidikan ini sebelum sesi ujian pertama berlangsung.

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

Selepas anda dan anak anda berpuasa hati dengan jawapan yang diberi kepada setiap persoalan yang timbul, anak anda perlu membuat keputusan samada ingin terlibat atau tidak dalam penyelidikan ini. Sebagai ibubapa, anda boleh hadir di semua sesi ujian/latihan sekiranya anak anda menginginkan begitu.

How do my child agree to participate in this research? / *Bagaimana anak saya boleh bersetuju terlibat?*

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

Sekiranya anak anda berminata untuk terlibat, anda perlu menandatangani borang persetujuan penjaga (Consent Form), manakala anak anda perlu mengisi dan menandatangani 'Assent Form' dan mengembalikannya kepada Michael Rumpf sebelum terlibat dengan sebarang ujian dimana-mana peringkat penyelidikan ini. Sayugia diingatkan anak anda tidak boleh terlibat dalam penyelidikan ini sekiranya anda dan anak anda tidak menandatangani borang-borang berkaitan.

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

Sekiranya anak anda tidak ingin terlibat dalam penyelidikan ini, beliau atau anda sendiri masih perlu memaklumkan kepada penyelidik. Ingin diingatkan di sini bahwa anak anda boleh menarik diri dari penyertaan pada bila-bila masa tanpa sebarang akibat.

Will my child receive feedback on the results of this research? / *Adakah anak saya akan menerima maklumbalas daripada dapatan kajian ini?*

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

Ya, beliau akan menerima ringkasan dapatan kajian beliau apabila semua maklumat telah sedia untuk diedarkan (selesai dianalisa dalam hujung Disember 2011). Sila tandakan di dalam kotak berkaitan di dalam 'Consent Form' sekiranya anda inginkan maklumat ini.

What do I do if I have concerns about this research? / *Apa yang saya patut buat sekiranya ada keraguan berhubung kajian ini?*

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

Sebarang keraguan berkaitan projek penyelidikan ini boleh berhubung terus dengan Penyelia Projek, Dr. John Cronin, john.cronin@aut.ac.nz, telefon: 09 921 9999, sambungan 7523.

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

Keraguan berkaitan cara penyelidikan ini dijalankan boleh berhubung terus dengan Setiausaha Eksekutif, AUTEC, Madaline Banda, Madeline.banda@aut.ac.nz, telefon: 09 921 9999, sambungan 8044.

Whom do I or my child contact for further information about this research? / *Siapa yang saya dan anak saya patut berhubung untuk maklumat lanjut kajian ini?*

Please contact the student researcher, Michael Rumpf, mrumpf@aut.ac.nz, mobile 0226 008 226 or the Dr. Nur Ikhwan Mohamad, nur.ikhwan@fsskl.upsi.edu.my

Sila berhubung terus dengan penyelidik, Michael Rumpf, mrumpf@aut.ac.nz, telefon bimbit 0226 008 226 atau Dr. Nur Ikhwan Mohamad, nur.ikhwan@fsskl.upsi.edu.my

Student Researcher Contact Details / *Maklumat Penyelidik Pelajar:*

Michael Rumpf, mrumpf@aut.ac.nz, mobile 0226 008 226

Project Supervisor Contact Details / Penyelia Projek:

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

Approved by the Auckland University of Technology Ethics Committee on 3/8/2011: AUTEC Reference number: 11/149.

***Diluluskan oleh Jawatankuasa Etika Auckland University of Technology pada: AUTEC Reference number* 11/149.**

Appendix 4: Consent forms

05 March 2010 page 1 of 1

Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: Reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children

Project Supervisor: Dr John Cronin

Researcher: Michael Rumpf

- O I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
- O I have had an opportunity to ask questions and to have them answered.
- O I understand that my child may withdraw him/herself or any information that he/she has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- O My son/daughter does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his/her physical performance (or that might be aggravated by the tasks requested), or any infection
- O I agree to let my child take part in this research.
- O I wish to receive a copy of my child's individual results from this research project (please tick one): YesO NoO
- O I would like to be invited to group information session to hear about the main findings from this research project (please tick one): YesO NoO

Participant's name: ....

Participant's guardians signature: ....

Participant's guardians name: ....

Participant's Contact Details (if appropriate):

....

....

....

Email:..

Date:

Approved by the Auckland University of Technology Ethics Committee on 08.02.2010, AUTEC Reference number 09/291

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

This version was last edited: 18 August 2009

Consent Form

Project title: The effect of strength/resisted training methods on sprinting and jumping performance in boys

Tajuk Projek: *Kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan remaja lelaki*

Project Supervisor / Penyelia Projek: Dr John Cronin

Researcher / Penyelidik: Michael Rumpf

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
Saya telah membaca dan memahami maklumat yang disediakan berkaitan penyelidikan ini di dalam borang maklumat (Information Sheet) bertarikh dd mmmm yyyy

○ I have had an opportunity to ask questions and to have them answered.
Saya telah mempunyai peluang untuk bertanyakan soalan dan menerima jawapan yang diperlukan.

○ I understand that my child may withdraw himself or any information that he has provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
Saya memahami bahawa anak saya boleh menarik diri mereka atau mana-mana maklumat yang mereka telah berikan untuk projek ini pada bila-bila masa, tanpa sebarang akibat.

○ My son does not suffer from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs his physical performance (or that might be aggravated by the tasks requested), or any infection
Anak saya tidak menghidap sebarang penyakit jantung, darah tinggi, mana-mana masalah pernafasan (termasuk asma), sebarang penyakit atau kecederaan yang akan memberi kesan pada prestasi fizikal beliau (atau yang akan bertambah parah akibat aktiviti yang akan dijalankan), atau sebarang jangkitan.

○ I agree to let my child take part in this research.
Saya bersetuju membenarkan anak saya mengambil bahagian dalam penyelidikan ini.

○ I wish to receive a copy of his individual results from this research project (please tick one):
Saya ingin menerima salinan dapatan ujian anak saya (sila tanda salah satu):
Yes○ No○ / *Ya○ Tidak○*

○ I would like to be invited to group information session to hear about the main findings from this research project (please tick one):
Saya ingin dijemput ke sesi makluman berkumpulan untuk mendengar berkaitan dapatan utama daripada kajian ini (sila tanda salah satu):
Yes○ No○ / *Ya○ Tidak○*

Participant's signature : ....
Tandatangan peserta

Participant's guardians signature: ....
Tandatangan penjaga

Participant's name: ....
Nama peserta

Participant's Contact Details (if appropriate) / *Maklumat peserta (jika perlu):*

....

....

....

Email:...

Date / *Tarikh:*

***Approved by the Auckland University of Technology Ethics Committee on 3/8/2011, AUTEC Reference number:* 11/149**

***Diluluskan oleh Jawatankuasa Etika Auckland University of Technology 3/8/2011, AUTEC Reference number:* 11/149**

Note: The Participant should retain a copy of this form.
Nota: Peserta sepatutnya menyimpan salinan borang ini.

Appendix 5: Assent forms

Assent Form

Project title:	Reliability and contribution of variables measured on a non-motorised Woodway treadmill for predicting sprint velocity in children
Project Supervisor:	Dr John Cronin
Researcher:	Michael Rumpf

- O I have read and understood the sheet telling me what will happen in this study and why it is important.
- O I have been able to ask questions and to have them answered.
- O I understand that notes will be taken during the testing.
- O I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- O If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.
- O I agree to take part in this research.

Participant's signature: ....

Participant's name: ....

Participant Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on 08.02.2010 AUTEC Reference number 09/291

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

Assent Form

Project title: The effect of strength/resisted training methods on running and jumping performance in boys
Tajuk Projek: *Kesan kaedah latihan kekuatan/rintangan ke atas prestasi pecutan dan lompatan di kalangan remaja lelaki*

Project Supervisor / Penyelia Projek: Dr John Cronin

Researcher / Penyelidik: Michael Rumpf

○ I have read and understood the sheet telling me what will happen in this study and why it is important.
Saya telah mebaca dan memahami borang maklumat yang menerangkan apa yang akan terjadi dalam penyelidikan ini dan kenapa ianya penting.

○ I have been able to ask questions and to have them answered.
Saya telah diberi peluang bertanyakan soalan dan pihak penyelidik telah menjawapnya.

○ I understand that I will be filmed during the testing.
Saya mengetahui bahawa saya akan dirakam sewaktu ujian dijalankan.

○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
Saya memhami bahawa sewaktu proses kutipan data berjalan, saya tetap boleh menarik diri pada bila-bila masa dan tiada apa-apa akan berlaku akibat tindakan menarik diri saya ini.

○ If I stop being part of the study, I understand that all information about me, including the recordings or any part of them that include me, will be destroyed.
Sekiranya saya berhenti dari terlibat dalam penyelidikan ini, saya faham bahawa semua maklumat berkaitan saya, termasuk segala rakaman yang melibatkan saya, akan dimusnahkan.

○ I agree to take part in this research.
Saya bersetuju untuk terlibat dalam penyelidikan ini.

Participant's signature: ....
Tandatangan peserta

Participant's name: ....
Nama peserta

Participant Contact Details (if appropriate) / *Maklumat peserta (sekiranya perlu):*

....

....

....

....

Date / *Tarikh:*

Approved by the Auckland University of Technology Ethics Committee on 3/8/2011; AUTEC Reference number: 11/149

Diluluskan oleh Jawatankuasa Etika Auckland University of Technology pada nombor rujukan AUTEC 3/8/2011; AUTEC Reference number: 11/149

Note: The Participant should retain a copy of this form.
Nota: Peserta sepatutnya menyimpan salinan borang ini

Appendix 6: Abstracts

Chapter 2

The primary purpose of this paper was to provide insight into the methodological issues and associated reliability of assessments used to quantify running sprint ability in youth athletes aged 8 – 18 years. Over-ground sprinting was the most reliable and common used choice of assessment to measure sprint performance of youth. In addition, the performance data of those athletes over distances ranging from 5 to 40 metres was collated from 34 published articles and tabulated with regards to the athlete's chronological age. Torque or non-motorised treadmills have been used to quantify sprint performance in youth with acceptable reliability, this technology providing deeper insight into sprint kinetics and kinematics; however, there is limited performance data on youth using the torque and the non-motorised treadmill. It is suggested that future research should utilise this technology in youth to better understand changes associated with growth, maturation and training.

Chapter 3

The primary purpose of this paper was to provide insight into the effect of different training methods on sprinting time in male youth aged 8 – 18 years. Specific and non-specific training methods were identified, the participants of the fiveteen studies chategorised into pre-, mid- and post-peak height velocity and effect sizes and percent changes calculated for each training method were appropriate. Plyometric training had the most effect on sprint times in pre- and mid-peak height velocity participants, while combined training methods were the most efficient in post-peak height velocity participants. However, it is difficult to quantify the effects of different training methods due to the limited knowledge in this area e.g. resisted training on pre-PHV participants. Furthermore, it may be worthwhile to investigate additional variables (i.e. stride length, stride frequency, horizontal force), to better determine effect of training methods in different maturity status, the development of sprinting and possible stages where individual development can be optimised by training.

Chapter 4

Sprint training methods were classified as specific (resisted and assisted sprinting, and non-assisted sprinting), non-specific (strength, power and plyometric training) and a combination of both methods. The effects of these methods on the sprint times of recreational and well-trained athletes were quantified via percent changes (%change) and effect statistics (ES). Combined training methods resulted in the greatest decrease in sprint times in trained athletes (ES = -0.55 ± 0.48, %change = -2.17 ± 2.56), while resisted sprinting decreased sprint times of recreational athletes the most (ES = -2.00 ± 2.21; %change = -1.73 ± 2.39).

Chapter 5

The purpose of this study was to quantify the reliability of kinematic and kinetic variables and to present normative data of those variables using a sample of pre-peak-height-velocity (PHV) male athletes sprinting on a non-motorised treadmill. Twenty-five participants performed three 5-seconds all-out sprints from a standing split start on a Woodway non-motorised treadmill on three separate occasions. Percent change in the means (-3.66 to 3.35%) and coefficients of variation (0.56 to 7.81%) were thought reliable for all variables. However, average step rate, average horizontal force and average vertical force did not meet the standards (≥ 0.70) set for acceptable intraclass correlation coefficients (ICC). Due to the homogeneous group it was expected to receive low ICC values. Therefore, youth sprinting performance can be tested reliably on a Woodway non-motorised treadmill, especially if the percent change in the mean and CV are deemed the important reliability measures.

Chapter 6

The purpose of this study was to investigate the effect of four different step detection thresholds (10, 15, 20, 30% body mass - BM) on sprint kinetics and kinematics as measured on a Woodway non-motorised treadmill (NMT) in a youth population in pre-peak-height-velocity (PHV) state. A total of 16 pre-PHV athletes sprinted 30 metres from a split start position. Of the 15 variables measured, significant differences ($p < 0.05$) were found in 5 kinematic (step length, vertical displacement, contact time, eccentric and concentric time) and 2 kinetic (vertical and leg stiffness) variables between the 10 versus 20 and/or 30% BM step detection thresholds. Contact time was also significantly different between 15 vs. 30% BM step detection thresholds. In terms of reliability, the 15 and 30% BM step detection thresholds were found the most stable across all variables (average coefficient of variation (coefficient of variation = ~6.0%). Given this information, a step detection threshold of 15% BM is recommended for quantifying kinematic and kinetic variables on a NMT, as this threshold seems to account for signal variability appropriately without compromising reliability.

Chapter 7

The purpose of this study was to investigate the kinematics and kinetics associated with maximum sprint velocity in male youth participants of different maturity status (pre-, mid- and post-peak height velocity (PHV)). Participants (n = 74) sprinted over 30 metre on a non-motorised treadmill and the fastest four steps were analysed. Pre-PHV participants were found to differ significantly ($p < 0.05$) to mid- and post-PHV participants in speed, step length, step frequency, vertical and horizontal force, and horizontal power (~8 to 78%). However, only relative vertical force and speed differed significantly between mid- and post-PHV groups. The greatest average percent change in kinetics and kinematics was observed from pre- to mid-PHV (37.8%) compared to mid- to post-PHV groups (11.6%). The two best predictors of maximal velocity across maturation were power and horizontal force (r^2 =97-99%) indicating the importance of the specific force direction whilst sprinting.

Chapter 8

The purpose of this study was to investigate the vertical and leg stiffness and stretch shortening cycle during sprinting in developing athletes in different maturity status. Seventy-four developing athletes between 8 and 16 years of age were categorised in pre-, mid-, and post-peak height velocity and sprinted for 30 metres on a non-motorised treadmill.

Chapter 9

The purpose of this study is to quantify the magnitude of asymmetry in a number of kinetic variables during a running task in male youth of different maturity status. Inter-limb leg asymmetries whilst sprinting on a non-motorised treadmill were measured in youth non-injured athletes in pre-, mid-, and post-pubescent status. Averaged over all maturity status, asymmetries in vertical force (19.7%), horizontal force (15.0%), work (19.5%) and power (15.4%) were observed. Positive work was the only variable found to differ significantly ($p < 0.05$) between maturity status, significantly greater asymmetries were found in pre-pubescent (26.4%) compared to mid- and post-pubescent (~14 to 17%) athletes. As the population in this study was characterised as non-injured, asymmetries of 15-20% appeared typical during a running task in developmental athletes.

Chapter 10

The purpose of this study was to investigate the effect of 2.5, 5, 7.5 and 10% body mass load on resisted sled towing 30 metre sprint times in male youth athletes of different maturity status. A total of 35 athletes (19 pre-pubescent and 16 mid-/post-pubescent) sprinted three times in an unloaded and each of the loaded conditions. The pre-pubescent athletes were significantly slower (~33%; $p < 0.05$) than the more mature athletes across all loads (unloaded, 2.5, 5, 7.5, 10% body mass). Each incremental load (i.e. 2.5% body mass) was found to reduce 30 m sprint times by ~3% and ~2.3% for the pre- and mid-/post-pubescent respectively. The slopes of the pre~ and mid/post regression equations were compared and found to be statistically different ($p = 0.004$) suggesting that athletes of different maturity status respond differentially to the same relative resisted sprint load. Ten percent body mass load resulted in a deduction of sprint time of 13 and 9.9% for the pre- and mid-/post-pubescent respectively. These results enable predictive equations to be formulated and appropriate resisted sprint loading, based on the intended focus of a session.

Chapter 11

The purpose of this study was to investigate the effect of resisted sled towing training on maximal sprint velocity in youth of different maturity status.

A total of 32 children, 18 pre-peak-height-velocity (PHV) and 14 mid-/post-PHV, were tested for 30 metre sprint performance on a non-motorised treadmill. The intervention consisted of 16 sessions within 6 weeks of resisted sled towing training with 2-3 sessions per week and 8-10 sprints over 15 to 30 metres with a load of 2.5, 5, 7.5, or 10% body mass (BM) for each training session. While pre-PHV participants did not improve sprint performance after the training, the mid-/post-PHV participants had significantly better sprint performance, as demonstrated by a significant reduction (%change, ES) in sprint time (-5.76, -0.74), relative leg stiffness (-45.0, -2.16) and relative vertical stiffness (-17.4, -0.76) and a significant increase in average velocity (5.99, 0.76), average step rate (5.65, 0.53), average power (6.36, 0.31) and average relative vertical forces (3.45, 1.70). The training induced improvements in sprint time, average velocity, peak power, peak horizontal force and relative vertical force were significantly greater in the more mature athletes (mid-/post-PHV participants) and indicated a better response to the training compared to the pre-PHV group. In conclusion, resisted sprint training was less effective in the pre-PHV groups, however, can be used as a suitable training method in mid-/post-PHV athletes to improve 30 metre sprint performance.