The Physical Power Pre-requisites and Acute Effects of Resisted Sled Loading on Sprint Running Kinematics of the Early Acceleration Phase from Starting Blocks.

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CERTIFICATE 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 qualification of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgements are made in the acknowledgements.

Chapters 3 – 5 of this thesis represent three separate papers that will be submitted to peer-reviewed journals in consideration for publication. In each of these papers, 90% of the work is my own, with the remaining 10% contribution from Mr. Justin Keogh and Dr Elizabeth Bradshaw. All of these coauthors have approved the inclusion of the joint work in this Masters thesis.

Peter Scott Maulder

Date: 31st January 2005

DEDICATION

I wish to dedicate this thesis to my best friend and companion for life, Antoinette my beautiful wife. The completion of this thesis (on time) would not have been possible without your understanding, love and support throughout the duration of this thesis. Thank you so much, love you always.

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NOTE TO READER

This thesis is presented as a series of chapters for its submission format. The chapters are presented as an introduction, literature review, followed by three scientific research papers, thesis discussion, and finally a chapter dedicated to coaching applications that operate in synergy to construct a comprehensive representation of the technical and resistance training strategies for the sprint (block) start and early acceleration phases of sprint running.

In some instances of the thesis due to its chosen submission format parts will appear repetitive. This thesis fulfills the Auckland University of Technology Master of Health Science guidelines by constructively critiquing previous literature pertinent to sprint (block) start and early acceleration sprint running, and provides a broad experimental application to this growing body of knowledge.

PUBLICATIONS

Scientific Publications

The following three manuscripts are in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis.

Maulder, P. S., Keogh, J. W. L., & Bradshaw, E. J. (2005). The identification of the best sprint start performance measure of early acceleration sprint performance and its kinematic determinants. (Target Journal – Sports Biomechanics)

Maulder, P. S., Bradshaw, E. J., & Keogh, J. W. L. (2005). Resisted sled training methods for early acceleration sprint performance from starting blocks: Kinematic alterations due to different loading schemes. (Target Journal – Sports Biomechanics)

Maulder, P. S., Bradshaw, E. J., & Keogh, J. W. L. (2005). Physical and training pre-requisites for start and sprint acceleration performance with and without sled resistance. (Target Journal – Sports Biomechanics)

Conference Proceedings

One published conference abstract has resulted from the work presented in this thesis.

Maulder, P. S., Keogh, J. W. L., & Bradshaw, E. J. (2004). Physical and training pre-requisites for start and sprint acceleration performance. Sports Medicine and Science New Zealand conference. Auckland. Page 130.

ABSTRACT

The ability to perform well during the sprint start and early acceleration phases of sprint running is critical. Many forms of training interventions are utilised to give a sprinter a competitive edge over their opponents in these particular phases. Despite this fact, there has been limited research on the technical and power type training strategies appropriate to improve sprint kinematics and the associated sprint performance in the sprint start and early acceleration phases.

PURPOSE: To determine the best sprint start and early acceleration phase kinematic determinants, investigate the effect that load has on the kinematics of the sprint start and early acceleration performance and to determine how various physical characteristics may influence both resisted and unresisted sprint running.

METHODS: Ten male track sprinters (mean ± *SD:* age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 ± 0.36 s {10.37 – 11.42 s}) attended two testing sessions. The first session required the athletes to sprint twelve 10 m sprints from a block start under unresisted and resisted (10% & 20% body mass) sled conditions. The second session required each athlete to complete an anthropometric assessment (height, mass, 3 bone lengths, 2 bone widths) and a variety of vertical (squat jump, countermovement jump, continuous straight legged jump) and horizontal (single leg hop for distance, single leg triple hop for distance) jump tests (3 trials each). Centre of gravity, joint and segment kinematics were calculated from 2D analysis utilising a kinematic analysis system (Ariel Performance Analysis System, U.S.A.). Means and standard deviations are presented for kinematic and performance measures. Pearson's product-moment correlation coefficients were employed to establish relationships between sprint start (block) performance variables and 10 m sprint performance. A linear regression analysis was used to quantify the relationships between the dependent variables (start performance and 10 m sprint time) and selected kinematic independent variables. ANOVA's with repeated measures were used to determine if there was a significant interaction between the kinematics under the various loaded conditions. A stepwise multiple regression and linear regression analysis were used for the prediction of unresisted and resisted sprint times from anthropometrical and functional performance measures.

RESULTS: Mean horizontal block acceleration was identified as the start performance variable with the strongest relationship to 10 m sprint time. The most significant kinematic predictors of mean horizontal block acceleration were a large horizontal block velocity, short start time, and low thigh angle of the front block leg with respect to the horizontal at block takeoff. Sprint time over 10 m was best predicted by a large mean horizontal block acceleration (sprint start performance), increased angle of the front arm shoulder at step takeoff, and increased angle of front upper arm at step takeoff. Sprint start kinematics significantly altered as a result of resisted sled towing were start time (increase) and push-off angle from the blocks (decrease). Step length, stance time and propulsion time significantly increased, whereas flight time and flight distance significantly decreased under loaded conditions. A load of 20% body mass was revealed to be the better training load to utilise during resisted sled sprinting, especially for athletes who performed faster than 2.10 s for a 10 m sprint from a block start. The countermovement jump exercise was a strong predictor of both 10 m and 100 m sprint time. The continuous straight legged jump test was revealed to be a good predictor of resisted sprints over 10 m.

CONCLUSION: Consideration should be given to the technical training aspects of sprint start performance and forceful arm movements during step takeoff for improving sprint start and early acceleration sprint performance from starting blocks. These technical training aspects should also be supplemented with resisted sled towing with a load of 20% body mass and countermovement jump training to improve sprint ability.

CHAPTER ONE

Introduction

Introduction

The 100 m and the 200 m sprints are amongst the most celebrated and observed track and field events of the modern Olympic program. The 100 m event is often among the most eagerly awaited and watched events of a competition (Moravec et al., 1988). Success in this event involves the ability to cover the respective distance in the shortest time possible. Over the last nine decades the world record for the 100 m sprint has been broken fifteen times, which can be observed in Table 1.1. However, a difference of approximately 0.8 s separates the first reported 100 m time of 10.6 s, performed by Donald Lippincott in 1912, and the current 100 m world record time of 9.78 s, held by Tim Montgomery from the U.S.A. The improving trends in 100 m times are thought, to some extent, to be the result of improvements in training methods, starting and running techniques, and track surfaces (Moravec et al., 1988).

Table 1.1. 100 m world record sprint times

Athlete	Country	Year	Time (s)
Tim Montgomery	USA	2002	9.78
Maurice Greene	USA	1999	9.79
Donovan Bailey	Canada	1996	9.84
Leroy Burrell	USA	1994	9.85
Carl Lewis	USA	1991	9.86
Leroy Burrell	USA	1991	9.90
Carl Lewis	USA	1988	9.92
Calvin Smith	USA	1983	9.93
Jim Hines	USA	1968	9.95
Armin Harry	Germany	1960	10.0
Willie Williams	USA	1956	10.1
Jesse Owens	USA	1936	10.2
Percey Williams	Canada	1930	10.3
Charles Paddock	USA	1921	10.4
Donald Lippincott	USA	1912	10.6

Whilst sprint running appears a simple task, many authors have suggested that it is a multidimensional skill made up of a number of phases(Delecluse et al., 1995; Johnson & Buckley, 2001; Mero, Komi, & Gregor, 1992). Success in sprint running therefore requires an athlete to optimally integrate all of these phases into their performance. A 100 m sprint can be divided into three specific performance phases

(Johnson & Buckley, 2001). The first phase involves the generation of high accelerations over the initial 10 m, the second phase continues this acceleration up to the attainment of maximal running speed (10 – 36 m), and the third phase is the maintenance of this maximal speed over the remaining distance (36 – 100 m).

According to the ruling of the International Amateur Athletic Federation (IAAF) athletes must perform a crouch start from starting blocks. Sprint start performance and the early acceleration phases (10 m) have been suggested to be critical to overall sprint performance in track and field events (Coh, Jost, Skof, Tomazin, & Dolenec, 1998; Harland & Steele, 1997). Many athletes that have been top three placed in recent world championship 100 m sprint events are the fastest to react in the starting blocks, and also the fastest to a distance of 10 m, which can be observed in Table 1.2 (Ae, Ito, & Suzuki, 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997). Strong relationships have also been reported between 100 m sprint ability and that of block leaving velocity (r = -0.70) and velocity attained to 10 m (r = -0.81) (Mero, 1988).

Table 1.2. Reaction, first 10 m interval, and 100 m times of the three placed athletes from world championship men events (adapted from the results of Ferro et al., 2001, Muller & Hommel, 1997, Ae et al., 1992, & Moravec et al., 1988).

Year	Athlete	Reaction (s)	0-10m (s)	100m (s)
1999	Maurice Greene	0.132	1.73	9.80
	Bruny Surin	0.127	1.75	9.84
	Dwain Chambers	0.140	1.73	9.97
1997	Maurice Greene	0.134	1.71	9.86
	Donovan Bailey	0.145	1.77	9.91
	Tim Montgomery	0.134	1.73	9.94
1991	Carl Lewis	0.140	1.74	9.86
	Leroy Burrell	0.120	1.71	9.88
	Dennis Mitchell	0.090	1.71	9.91
1987	Ben Johnson	0.109	1.73	9.83
	Carl Lewis	0.196	1.74	9.93
	Raymond Stewart	0.235	N/a	10.08

The sprint start has been subject to a wealth of biomechanical analyses, such as EMG studies, kinetic studies, and kinematic studies. It is well understood that a good sprint start can be attributed to the ability to develop large horizontal forces at a high rate, not only in the blocks but in the subsequent strides (Harland & Steele, 1997). However, it is still unclear as to what field measure best represents a successful start. Some coaches and researchers have used a number of sprint start performance measures. These include horizontal start velocity (Coh et al., 1998; Mero, 1988; Mero & Komi, 1986; Mero, Luhtanen, & Komi, 1983; Schot & Knutzen, 1992; Young, McLean, & Ardagna, 1995), start time (Coh & Dolenec, 1996; Coh et al., 1998), and mean horizontal start acceleration (Delecluse, Van Coppenolle, Diels, & Goris, 1992). Whilst sprint start performance can be gathered from variables such as 10 m time, what happens between 0 and 10 m may affect such analyses. Therefore a variable independent of this phase needs to be considered. Identifying the most appropriate start performance measure would enable a more informed decision on what measure to use in both research and the field. Additionally, identifying the key kinematic predictors of that particular start performance measure will allow for the refinement of training strategies by the coach and athlete.

After the block start the athlete attempts to generate a high horizontal velocity. This is the product of the step length and step rate, which are in turn determined by stance and flight distances and times (Hunter, Marshall, & McNair, 2004a). If an athlete wishes to increase their horizontal velocity it can be achieved by increasing either step length or step frequency (Hunter et al., 2004a). Therefore finding training methods that emphasise the development of these step kinematics are of great importance. However, consideration must be given to the chance of a negative interaction occurring where one kinematic variable increases at the expense of the other (Hunter et al., 2004a).

Optimal sprint technique varies noticeably at different stages of a 100 m or 200 m race. Therefore, training strategies used to maximize performance in the maximum velocity or deceleration phases may not contribute to improvements in the start phase. Consequently, there is a need for research specifically targeted at the sprint start and early acceleration phase of a sprint. Prior to developing training interventions, however, an understanding of how these potential techniques affect sprint mechanics in an acute sense is needed.

A variety of interventions are used to improve sprint performance (Saraslanidis, 2000). Many training strategies employed by coaches and conditioners to enhance sprint start and early acceleration performance have no solid empirical evidence to support claims that they improve sprint performance. Although the sprint start has been the subject of numerous biomechanical analyses, few have attempted to examine the effects of various training strategies on sprint start and early acceleration performance. Resisted sled training and plyometric training, for example, are commonly used by sprinters in an attempt to improve their performance.

Resisted sled towing has been suggested as the most appropriate sprint training technique to improve the strength of the muscles that contribute to sprint performance (Mouchbahani, Gollhofer, & Dickhuth, 2004; Saraslanidis, 2000; Sheppard, 2004). Not only is this method specific in nature to sprinting, but it stimulates greater whole-body force output than normal sprint running. Resisted sprint training is employed by coaches and conditioners in the belief that it will improve early acceleration performance. Empirical evidence is not available on this training method, such that the long term neuromuscular adaptations associated with this type of training are not known. Acute biomechanical analysis has demonstrated that resisted sled towing alters the sprint kinematics of females using a standing start (Letzelter, Sauerwein, & Burger, 1995) and male athletes participating in various field sports (Lockie, Murphy, & Spinks, 2003). The proposed benefits of resisted sled training are an increased stride length (Delecluse, 1997), an increase in muscular force output of the lower body (Saraslanidis, 2000), and the development of specific recruitment patterns of fast-twitch muscle fibres (Lockie et al., 2003). All of these technical and neuromuscular components appear to be of some importance for a successful block start (Harland & Steele, 1997).

Additional research is required to investigate the acute effects of resisted sled towing at different loads on early acceleration sprinting from a block start. Investigation of the effects of different loading schemes is needed as it is still unclear what the appropriate magnitude of load is to induce a significant training effect. The results of such an analysis would increase the coach's understanding of the acute effects of resisted sled training and enable them to better utilise resisted sled training in the training programs of their sprinters.

Another issue of resisted sled towing practice that warrants research is the possible pre-requisites that an athlete may require to perform resisted sled sprinting appropriately. Often by increasing the load a more dramatic change in running technique occurs resulting in a slower sprint running. It is unknown what loading is required and at what point the loading becomes excessive. Perhaps, strength or sprint ability determines the most appropriate load to use that will not alter running technique too dramatically (Jakalski, 1998). It is plausible that particular loads may require certain levels of strength and power in order for the appropriate training stimulus to be achieved. However, there is little or no information on this topic; therefore, physical pre-requisites need to be identified. Additionally, the minimum muscular qualities (force / power) and / or loads an individual may need, to successfully perform resisted sled towing warrants further understanding. Furthermore, information is required investigating whether or not the associated pre-requisites required for resisted sled sprinting are similar to that of unresisted sprinting.

Plyometric training, specifically jump training is utilised to increase the power output of the lower limb musculature. It is intended that the power developed through these jump exercises will transfer to greater power output during sprint running. There is a wide variety of jumps that can be chosen and utilised during training. Jumps can be acyclic (single expression of power – single jump) or cyclic (multiple expression of power – multiple jumps) in nature, which can be performed in either the vertical, horizontal or lateral directions. Take-off power from jump exercises reportedly have varying relations with early acceleration sprint performance (Kukolj, Ropret, Ugarkovic, & Jaric, 1999; Mero et al., 1992; Morin & Belli, 2003; Nesser, Latin, Berg, & Prentice, 1996; Young et al., 1995). Therefore, understanding what type of jump training is better suited to improving sprinting ability is required for the development of sprint-specific strength training programs.

Thesis Purpose

The general purpose of this thesis was to determine the best sprint start and early acceleration phase kinematic determinants, investigate the effect that load has on the kinematics of the sprint start and early acceleration performance and to determine how various physical characteristics may influence both resisted and unresisted sprint running.

Thesis Aims

The specific aims of this thesis were:

1. To determine the best block start performance measure. Examine the kinematic determinants of block start performance and early acceleration (10 m) sprint performance.

2. To examine the effect of different loads of resistance during resisted sled towing on the sprint running kinematics of the early acceleration phase from starting blocks.

3. To identify the physical pre-requisites for resisted and unresisted sprint acceleration performance from a block start.

4. Provide practical coaching applications for sprint athletes and coaches of sprint athletes.

Thesis Significance

It is still inconclusive whether explosive power training strategies used to enhance running performance during the early acceleration phase of a sprint from starting blocks are appropriate. The lack of empirical evidence to justify many training strategies (e.g. resisted sled training, jump training) is problematic, as the performance changes they supposedly induce is not well understood. The current study has significance for coaches, sport scientists, and physical conditioners who are continuously striving to improve the sprint running performance of their athletes. With sprint running arguably being a multidimensional task, training strategies that are ideal for the maximal velocity sprint phase may not induce similar results for the early acceleration phase or block start. Each specific training exercise may provide certain advantages or disadvantages to a given athlete depending on the requirements of each sprint phase. This research will provide information from which informed decisions on the choice of training exercises can be made aiding in optimal training prescription. Furthermore, this research may also provide the structure for additional research into technical, resisted sprinting, and jump strategies.

Thesis Limitations and Delimitations

The information provided within this study although useful has some limitations and delimitations. The main limitations and delimitations of this thesis must be addressed that may affect the generalisation of the results. Firstly from a methodological perspective the participant characteristics will be considered. A homogeneous group of athletes was used in this thesis (male track sprinters of regional and national level). The findings may not necessarily apply to female athletes, those of other standards, or those who compete in different sporting pursuits. Also only ten sprint athletes were selected for this thesis. More participants would improve the statistical power of the findings. However, the sprint athletes who participated in the study were some of the fastest sprinters in the country at the time of the sprint testing.

Data were collected from a block start up to a distance of 10 m only. Performance measures and kinematics may differ when the intention is to sprint shorter or further distances. Also, sprint trials were performed individually which is not a true competitive environment. It may be that data collected in a competition environment better represent the most important variables for sprinting.

Also only kinematic variables during the sprint start and first three steps of sprint running were measured, where kinetic variables may exhibit stronger relationships and be better predictors of sprint start performance and early acceleration (10 m) performance. Additionally, changes in motor activity and ground reaction forces were not measured during the loaded conditions of resisted sled towing. Ideally starting blocks instrumented with strain gauges, electromyography (EMG), and a force plate mounted within a running track would be required to provide this type of information.

Track coaches of sprint athletes and sports scientists would be interested in the possible adjustments in sprinting kinematics which may occur as a result of prolonged exposure to resisted sled towing. The acute analysis used in this thesis did not address any longitudinal changes in kinematics after a training period and therefore can not answer this question.

Unresisted and resisted sled towing with different loads from a standing start or performed over longer distances may require different anthropometrical and power pre-requisites. Also there may be other types of jump assessments not used in this thesis that are better pre-requisites for the unresisted and resisted sprint conditions.

References for this chapter are included in the list of references on the last few pages of this thesis.

CHAPTER TWO

A Review of the Literature

Introduction

This review will identify and describe the phases of a 100 m sprint running race, with a particular focus on the sprint start and early acceleration phases. The results of electromyographic (EMG), kinetic, and kinematic analyses will be presented so to provide some insight into the technical considerations of these two running phases. The relationships between sprinting performance and strength and power measures will be discussed with the reliability of such measures also addressed. Finally, the research underlying power training and the limited research to date on resisted sprinting will be presented.

Performance Phases of a Sprint Event

Many authors have suggested that sprint performance is a multidimensional skill made up of many phases (Delecluse et al., 1995; Johnson & Buckley, 2001; Mero et al., 1992). Helmick (2003) divided a sprint race into the start (or block) phase which was made up of the two sub phases reaction time and start time, acceleration phase, maximal-velocity phase, and deceleration phase (see Figure 2.1). Furthermore, Johnson and Buckley (2001) stated a 100 m sprint (or the distance traveled) can be divided into three specific performance phases. The first phase generates high acceleration over the initial 10 m, the second phase continues this acceleration up to the attainment of maximal running speed (10 – 36 m), and the third phase is the maintenance of this maximal speed over the remaining distance (36 – 100 m). All of these phases are critical to an athlete's sprinting ability. The focus of this review is on the early acceleration phase from a block sprint start.

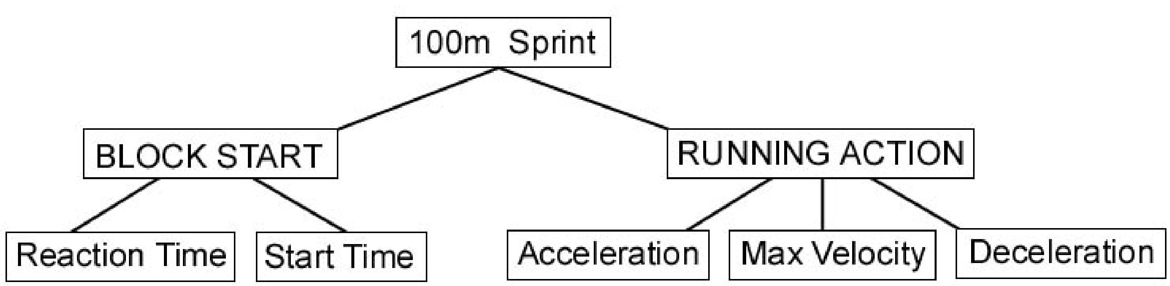


Figure 2.1. Phases of a 100 m sprint. (Adapted from Helmick (2003))

The Sprint Start from Starting Blocks

In a track and field sprint race the sprint start can be defined as the period from the ‘go’ signal (starter’s gun) to the moment of final contact of the front foot with the blocks or ground. The sprint start is considered to be one of the most important phases, directly influencing the final outcome of sprint performance (Coh et al., 1998; Harland & Steele, 1997; Helmick, 2003). In fact many athletes that have placed in the top three at recent world champion sprint events have been the fastest to react in the staring blocks (Ae et al., 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997). Therefore it is not surprising that extensive research has been conducted into the qualities of a good start over the past 70 years. Such studies have analysed a number of EMG, kinetic, and kinematic parameters, which will be discussed later in this section of the review.

Sprint Start Block Set-up

The first thing a sprint coach and athlete must consider with the sprint start is the set-up of the blocks at the starting line of the race. The aim of the block setup is to position the blocks in relation to the start line with the optimal angle of the block face in order to maximize block clearance. In order to achieve this optimal start the positioning of the front block in relation to the start line and the distance between the front and rear blocks must be considered. Furthermore, the block face which the feet push against must also be set at the optimal angle for the fastest start.

Block Positioning

There are three main types of block start commonly referred to in the literature. They are the bunched start, medium start, and elongated start (Harland & Steele, 1997; Hay, 1993; Schot & Knutzen, 1992). The main difference between these three starts is the difference in distance between the front block and the rear block (Hay, 1993). This distance is termed the “inter-block spacing”. Block positioning and inter-block spacing can be observed in Figure 2.2.

Figure 2.2. Inter-block spacing (a) and block positioning (b).

The bunched start has an inter-block spacing of generally 30 cm or less (Harland & Steele, 1997). During the bunch start the toes of the rear foot are approximately level with the heel of the front foot (Hay, 1993). This position brings the athlete's centre of gravity (C.G.) closer to the start line, which in turn would result in it being closer to the finish line (Helmick, 2003).

The medium start inter-block spacing range between 30 and 50 cm (Harland & Steele, 1997). Schot and Knutzen (1992) suggested the front block should be placed at a distance equal to 60% of the athlete's leg length from the start line, and a distance of 45% leg length for the inter-block spacing.

An inter-block spacing greater than 50 cm is considered an elongated start (Harland & Steele, 1997). Schot and Knutzen (1992) suggested the front block should be placed at a distance equal to 60% of the athlete's leg length from the start line, and a distance of 60% leg length for the inter-block spacing.

Each of these methods have certain theoretical advantages and disadvantages. The bunch start is useful for leaving the blocks in a short time but limits the production of impulse (force x time) (Henry, 1952). Henry (1952), Stock (1962), and Sigerseth and Grinaker (1962) reported that sprint performance was faster when performed with a medium start position compared to a bunched and elongated start. It has been theorized by Stock (1962), that a medium block spacing allows athletes to better utilise the extensor reflex of the calf muscles. An elongated block setup position has been discovered by researchers to be the less preferred start method (Henry, 1952;

Sigerseth & Grinaker, 1962). This was due to the overstretched position of the athlete in conjunction with too long a period which could be ineffective, aside from this however the ability to produce a larger impulse was more prevalent with this method. However, the findings of Schot and Knutzen (1992) suggested an elongated start to be a better start method as it resulted in a greater horizontal displacement at block clearance, a lower C.G. clearance, and greater horizontal velocities. The discrepancies in these studies could be due to the angles of the block faces of the front and rear blocks which can alter the force output, however the angles of the block faces were not reported.

It appears that the medium and elongated inter-block spacing methods are more advantageous for a better sprint start and sprint performance than the bunched method. However, consideration must be given to which of the two will be of better advantage to the athlete as it is unclear which method is best. It is also possible that inter-sprinter differences in anthropometry or strength may contribute to this, as these factors may influence the ability of each sprinter to use a certain starting block position.

Block Obliquity

Once an athlete has positioned their starting blocks on the track, the block faces in which the feet will rest against need to be placed at an angle where the athlete can maximize the force output of the lower limb musculature. The angle of these blocks with respect to the horizontal (ground) is referred to as block obliquity (Guissard, Duchateau, & Hainaut, 1992; Harland & Steele, 1997; Helmick, 2003). An example of block obliquity can be observed in Figure 2.3.

Figure 2.3. Block obliquity of the front and back block faces.

The effect of different block obliquities on muscle activity and horizontal start velocity was investigated by Guissard and colleagues (1992). Block obliquities of 30°, 50°, and 70° were used for the front block and the 70° angle was kept constant for the rear block. The authors reported that as block obliquity of the front block decreased from 70° to 30° horizontal start velocity and average horizontal acceleration increased. However, no significant change in the total duration of the push phase or the overall EMG activity occurred. By reducing the block obliquity the medial gastrocnemius and soleus muscle length would have been increased in the block start. This could have enhanced the subsequent stretch-shorten cycle (SSC) and its ability to contribute to the speed of muscle shortening.

These findings suggest that an athlete should employ a low angle of the front block face in order to increase force output without increasing the time in which the force is applied. Further research examining the responses due to changes in block obliquities of the rear block are warranted to identify if a further enhancement in start performance could occur.

Reaction Time Phase of the Sprint Start

Reaction time is an important sub-phase of the block start and for the purposes of the sprint events in track and field competitions, is the elapsed time between the firing of the starter's gun and the moment when the athlete increases the force against the starting blocks (Coh & Dolenec, 1996; Ditroilo & Kilding, 2004; Mero et al., 1992). During a race an athlete can anticipate the starter's signal and react too quickly, thus committing a false start. International Association of Athletics Federation (IAAF) rules have set a margin of 100 ms as the threshold for a false start. In the past each athlete in the race was permitted to perform one false start with the second resulting in disqualification, however, the new rules of the IAAF only allow one false start per race, with any further false starts (regardless of who commits them) resulting in disqualification of that athlete.

According to data provided by Moravec and co-workers (1988), Ae and colleagues (1992), Muller and Hommel (1997), and Ferro and associates (2001), an outstanding reaction time for a 100 m event is less than 0.140 s for elite male sprinters, and substandard is greater than 0.190 s. Ditroilo and Kilding (2004) suggested that the relationship between reaction time and sprint performance time of elite sprinters (100 m = 10.20 to 11.80 s) to be equivocal due to significant relationships being reported in one (Coh et al., 1998) but not all studies (Mero, 1988). However, the shorter the race the more important reaction time is to performance (Mero et al., 1992; Moravec et al., 1988). Data presented from world championship sprint competitions often reveal that those who are placed in the top three in the race were the faster reactors (Ae et al., 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997). Table 2.1 highlights the reaction times of the first three placed sprinters at world championship events. It should be noted that the performance of Dennis Mitchell in 1991 would have been considered a false start in that his reaction time was less than 100 ms.

These findings suggest that reaction time is critical for elite sprinters at International level (100 m = < 10.00 s) and highlights the importance of reaction time to 100 m sprint success. However, it is still unclear on the importance of reaction time for sprinters at a lower level (e.g. club, provincial) hence more research is required determining the importance of reaction time for sprint athletes at these levels.

Table 2.1. Reaction, first 10 m interval, and 100 m times of the three placed athletes from world championship men events (adapted from the results of Ferro et al., 2001, Muller & Hommel, 1997, Ae et al., 1992, & Moravec et al., 1988).

Year	Athlete	Reaction (s)	0-10m (s)	100m (s)
1999	Maurice Greene	0.132	1.73	9.80
	Bruny Surin	0.127	1.75	9.84
	Dwain Chambers	0.140	1.73	9.97
1997	Maurice Greene	0.134	1.71	9.86
	Donovan Bailey	0.145	1.77	9.91
	Tim Montgomery	0.134	1.73	9.94
1991	Carl Lewis	0.140	1.74	9.86
	Leroy Burrell	0.120	1.71	9.88
	Dennis Mitchell	0.090	1.71	9.91
1987	Ben Johnson	0.109	1.73	9.83
	Carl Lewis	0.196	1.74	9.93
	Raymond Stewart	0.235	N/a	10.08

Start Time Phase of the Sprint Start

The other sub-phase of the sprint start is the start time. The start time disregards reaction time, and is the duration of the push off action which involves the onset of muscle activity and force production (Coh & Dolenec, 1996; Coh et al., 1998; Delecluse et al., 1992; Mero et al., 1992). The average start time during a block start ranges between 0.36 - 0.39 s, depending on the group of sprinters tested (Mero, 1988; Mero et al., 1992; Mero et al., 1983). Intuitively thinking it would seem most advantageous to leave the starting blocks in the shortest starting time possible. However start time has been reported to yield weak relationships with sprint performance (Coh & Dolenec, 1996).

In order to obtain a better understanding of this sub-phase of the sprint start the technical and biomechanical aspects must be considered. The following subsections will focus on the EMG activity, kinetics and kinematics of the sprint start.

EMG Activity during the Sprint Start

EMG analysis allows for the understanding of the relative timing and magnitude of muscular activation during a particular movement. Few EMG studies have been conducted on the sprint start. Guissard and Duchateau (1990) reported that during the sprint start, male sprinters had a longer duration of muscle activity in the front leg in comparison to the rear leg. However, the muscle activation sequence was the same in both legs. Biceps femoris was recruited first followed by the quadriceps and triceps surae (gastrocnemius and soleus) muscles. The EMG behaviour of the rectus femoris differed to the other quadriceps muscles during the sprint start. The activity of the rectus femoris of the leg in the front block was restricted till the second half of the pushing phase, whereas a consistent weak contribution occurred throughout the entire muscular activation of the rear block leg. This may relate to the biarticular nature of the rectus femoris and the fact that when the hip is in a flexed position, the rectus femoris is unable to shorten and develop force.

Although, the study of Guissard and Duchateau (1990) provides insight into the leg musculature activation sequences during the sprint start, more research is required in this particularly examining the EMG activity of the gluteal muscles and muscles of the upper body. Such studies would provide further information on the muscles and their respective activation patterns that are critical to training for an improved sprint start performance. Also studies need to determine the relative activation of muscles so to determine which are most active and therefore most important to sprint performance.

Kinetics during the Sprint Start

Kinetic movement analysis attempts to define the forces causing a movement (Hamill & Knutzen, 1995). A successful sprint start has been attributed to the ability of the athlete to exert large horizontal forces (Baumann, 1976; Harland & Steele, 1997). This is made evident by the stronger relationships reported between block leaving velocity and horizontal compared to vertical force production (Mero, 1988; Mero et al., 1983).

Block Forces

Maximum and average horizontal block forces have been reported to be significantly larger for fast compared to less skilled sprinters (Mero et al., 1983). Mero (1988) reported moderately high correlations between block leaving velocity and maximum and average block horizontal forces (r = 0.63 – 0.66). Skilled sprinters generally applied less relative peak force on the front block compared with the rear block when starting, with rear block forces also being exerted more rapidly than the front block forces (Harland & Steele, 1997). The ability to produce large maximal and average horizontal block forces appears to not only be critical to start performance but it has been revealed to be a strong indicator of sprint performance during the early acceleration (0 – 10 m) phase (Mero et al., 1983). For example, Mero et al. (1983) reported a significant relationship between maximal horizontal block force and average velocity over the first 10 m (r = 0.52). A significant relationship was also revealed between average horizontal block force and average velocity to 10 m (r = 0.49) (Mero et al., 1983).

The literature suggests that maximal and average horizontal block force production capabilities in the starting blocks distinguish between superior sprinters and sprinters of lesser talent. Therefore, the ability to produce large maximal and average horizontal block forces in the starting blocks appears critical to sprint start and acceleration running performance.

Block Impulses

Block impulse is the product of the average block force and the time over which the force acts (Harland & Steele, 1997). The front block impulse has been suggested to be larger than the back block impulse due to the front lower limb pushing for twice as long than the rear lower limb (Harland & Steele, 1997). In accordance with the impulse-momentum relationship, start performance may be optimized by maximizing the horizontal block impulse. This is supported by the findings of Baumann (1976) who revealed faster sprinters produce a larger horizontal impulse (263 N.s) than sprinters of lesser ability (214 N.s). Also, moderate to strong correlations have been reported between block leaving velocity and horizontal impulse (r = 0.54 - 0.79), with these correlations being greater than that of vertical impulse (r = 0.45 - 0.69) (Mero, 1988; Mero et al., 1983).

Not only is horizontal block impulse important for start performance but it has been revealed to be a moderately strong indicator of acceleration phase ability. Mero, Luhtanen, and Komi (1983) discovered a moderate relationship between the average velocity produced during a 10 m sprint and horizontal block impulse (r = 0.55). Coh and colleagues (1998) observed strong relationships between this front block horizontal impulse and time to sprint 20 m and 30 m (r = -0.57 & -0.71 respectively) for male sprinters. Also, Coh and Dolenec (1996) reported the horizontal impulse produced by the rear leg in the starting blocks to be correlated with sprint time to 10 m, 15 m, and 20 m (r = -0.71, -0.74, & -0.73 respectively) for female sprinters.

In order to enhance start performance the attainment of as much horizontal impulse possible whilst in the starting blocks appears vital. The literature also indicates that horizontal impulse production in the blocks is considered important to the final outcome of sprinting short distances (0 -30 m).

Kinematics during the Sprint Start

A kinematic movement analysis examines motion characteristics from a spatial and temporal perspective without reference to the forces causing motion (Hamill & Knutzen, 1995). In this part of the review kinematics of the set position in the starting blocks and the start action until block takeoff will be addressed. The set position is the position that the sprinter acquires prior to the start signal and can be observed in Figure 2.4. The start action is from the start signal to the moment of leaving the starting blocks (see Figure 2.4).

Figure 2.4. Set position (a) and start action (b).

Set Position: Lower Body Kinematics

It has been suggested that stronger/faster sprinters can generate greater block leaving velocity due to more acute lower body joint angles in the set position which allow for a greater range of joint extension (Mero et al., 1983). This is made evident by Coh and colleagues (1998) who reported a more dorsiflexed position of the front leg in the starting blocks to be significantly related to 20 m sprint time ($r = 0.63$). Furthermore, good (10.80 s) male 100 m sprinters compared to average (11.50 s) male 100 m sprinters have been reported to utilise significantly lesser hip joint angles (greater hip flexion) of both the front (41° vs. 52°) and rear (80° vs. 89°) legs in the set position (Mero et al., 1983). However, no significant differences in knee angles of either the front or back leg in the blocks have been found between good (10.80 s) and average (11.50 s) male 100 m sprinters (Mero et al., 1983). Inter-limb differences in knee angle have been observed with greater flexion in the front (89 - 111°) than rear leg (118 - 136°) (Harland & Steele, 1997).

Set Position: Upper Body Kinematics

It has been suggested that the hands should be arched with only the finger tips touching the track surface, as this will ensure that the athlete will not apply too much weight to the arms (Helmick, 2003; Henry, 1952). Schot and Knutzen (1992) discovered that for an athlete to maintain other joint angles comfortably during the start position a shoulder angle of approximately 90° should be used as it decreases the amount of loading on the shoulder and arm musculature. However, it has been suggested for some sprinters that a slight forward lean at the shoulders relative to the vertical position may be of advantage (Harland & Steele, 1997). If too much weight is distributed across the shoulders and hands this could decrease the ability to remove the hands from the ground quickly.

Mero, Luhtanen, and Komi (1983) reported no significant differences in block set position trunk lean between good (10.80 s) and average (11.50 s) male 100 m sprinters. Trunk lean in the blocks for male sprinters has been reported to range between -9° and -21° relative to the horizontal position starting at the hip joint (Atwater, 1982; Mero, 1988; Mero et al., 1983).

Start Action Kinematics

An important aspect to consider when the athlete is leaving the starting blocks is the angle of takeoff. Hoster and May (1979) stated that the takeoff (drive) angle during block take-off should be as low (horizontal) as possible. This allows the horizontal component of block force to be maximized (Korchemny, 1992).

Bohn and co-workers (1998) reported that post the push-off from the starting blocks the knee angle of the forward movement leg (the leg that was in the back block) was 20° less for a faster athlete compared to the slower athlete. It was suggested that the lower knee angle of the swing leg resulted in a lower moment of inertia of the whole leg, therefore increasing angular velocity and acceleration resulting in a faster placement for the next step.

Although most of the sprint kinematic literature has focused on the lower body, a quick arm reaction (hands off ground) is thought critical in getting a fast start out of the blocks (Moss, 2000). The arms are shorter and lighter than the legs, hence have a lesser moment of inertia therefore are able to react quicker. Elite male sprinters have been reported to remove their hands from the ground in approximately 0.19 s to 0.23 s (Atwater, 1982).

<u>Sprint Start Performance</u>

In order to maximize sprint start performance, athletes need to produce the highest horizontal velocity in the shortest possible time (Coh & Dolenec, 1996; Delecluse et al., 1992; Helmick, 2003). Past research has used different means to distinguish sprint start performance, these include horizontal start velocity (Coh et al., 1998; Mero, 1988; Mero & Komi, 1986; Mero et al., 1983; Schot & Knutzen, 1992; Young et al., 1995), start time (Coh & Dolenec, 1996; Coh et al., 1998), and mean horizontal start acceleration (Delecluse et al., 1992). However, no consensus has been reached regarding the importance of these measures and which may best determine sprint running performance.

Horizontal start velocity at the moment of leaving the starting blocks is commonly used in many studies (Mero, 1988; Mero et al., 1983; Schot & Knutzen, 1992). Significant relationships between horizontal start velocity and sprint running performance have been reported for males but not females (Coh et al., 1998), with correlations ranging from r = -0.03 to -0.66 for distances between 10 and 30 m. The findings of Coh and colleagues (1998) suggest that the use of horizontal start velocity for evaluating sprint start performance may be gender specific due to the insignificant relationships reported between this start measure and sprint running performance for females. However, the reasons for this occurrence need further investigation in order to rule out the use of horizontal start velocity as a start performance measure for females. Nonetheless, it appears to be an adequate start measure to use when assessing the sprint ability of male sprinters.

Exiting the starting blocks in the shortest time possible has also been proposed to be important for sprint start performance. However, the literature on the relationships between start time and sprint performance appears equivocal. For example, Coh and Dolenec (1996) reporting a significant relationship between start time and 15 m time ($r = 0.70$) but not for start time and 10 m sprint performance ($r = 0.41$). Additionally, Baumann (1976) concluded that start time had very little to do with 100 m performance. Schot and Knutzen (1992) suggested that clearing the starting blocks in minimum time would not be beneficial if subsequent movements were constrained in their efficiency. It appears from these studies that the distance of the sprint may in some part explain the variations in correlations between start time and sprint performance. More research is required examing the relationship between start time and sprint performance over different distances ranging from 10 to 100 m.

Mean horizontal start acceleration, which is the derivative of horizontal start velocity and start time has also been proposed to be a sprint start performance indicator (Delecluse et al., 1992). Mean horizontal start acceleration was reported to be correlated ($r = 0.71$) with 12 m sprint speed (Delecluse et al., 1992). Therefore leaving the blocks in the optimal start time while producing a high horizontal velocity at the moment of leaving the starting blocks, seems to be related to sprint start performance.

Perhaps there are better performance measures such as the maximum velocity produced in the blocks, the mean horizontal velocity produced in the blocks, or a combination of start time and the mean horizontal velocity produced in the blocks to give mean horizontal block acceleration. Identifying which performance measure is best related to overall sprint performance will aid in a clearer understanding of the determinants of sprint running.

The Early Acceleration Sprint Running Phase

The early acceleration phase (10 m) has been suggested to be important to overall sprint performance in track and field (Coh et al., 1998; Harland & Steele, 1997). This is highlighted by the fact that many of the winners of the 100 m sprint event at a world champion level are the fastest to a distance of 10 m (Ae et al., 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997). Furthermore, Mero (1988) reported a strong relationship between an athletes average velocity over 10 m and their 100 m personal best time ($r = -0.81$, $p = 0.01$).

Gait Phases of Sprint Running

Sprint running is the integration of movements from both legs and actions of the upper body. The movements of the legs are known as strides or steps. A stride is a complete running cycle from foot contact with the ground to the next ground contact with the same foot (Cavanagh & Kram, 1989), whereas a step is defined as the moment from foot contact of one foot to the contact of the opposite foot and is representative of a half cycle (Hunter et al., 2004a). The action of the legs in sprinting are cyclic, each foot in turn lands on the ground, passes beneath and behind the body, and then leaves the ground to move forward again ready for the next landing (Hay, 1993). Based on the events of a single leg during the cycle of a stride there is a stance phase and a swing phase. The stance phase is where the individual is in contact with the ground, i.e. from touchdown of the foot to the takeoff of the foot. The stance phase can be further broken into a braking phase (negative horizontal reaction force) and a propulsion phase (positive horizontal reaction force) (Mero, Komi, and Gregor 1992). Once the foot leaves the ground it is in the swing phase in which the foot is being brought forward in preparation for the next stride. This cycle can be further broken down into an early swing, mid swing, late swing, early stance, and late stance phases (Johnson and Buckley 2001) (see Figure 2.5). At some stage throughout the cycle of the stride the athlete will be in the swing phase for both feet. During this flight phase the athlete has no contact with the ground and hence is considered a projectile. Accordingly the athlete is then subject to the laws of projectile motion at this time.

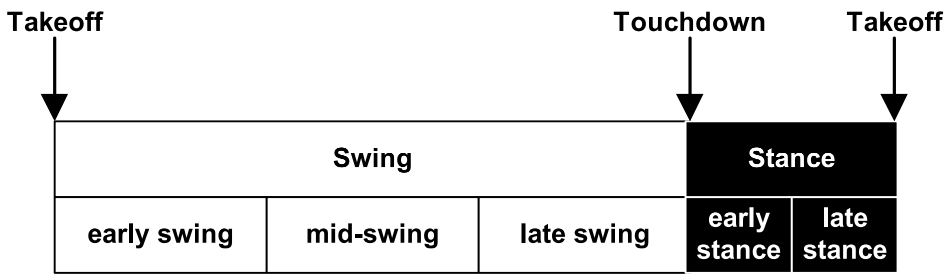


Figure 2.5. Subdivisions of a stride, based on the events of a single lower-limb

The early swing phase starts at the instant of takeoff and continues until the swinging thigh is approximately vertical (see Figure 2.6).

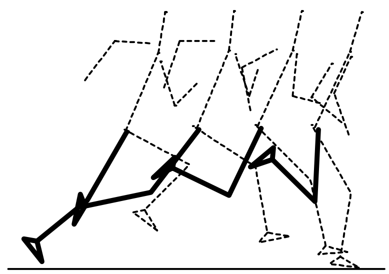


Figure 2.6. The early swing phase.

The mid-swing phase starts from when the swinging thigh is vertical and continues until the instant of maximum knee lift (see Figure 2.7).

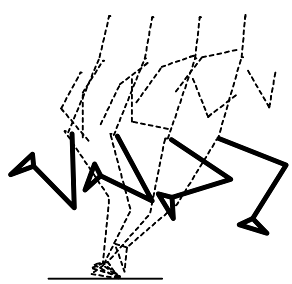


Figure 2.7. The mid-swing phase.

The late-swing phase starts with the swing limb in the 'high-knee position' and continues with the hip and knee extending in preparation for the upcoming touchdown (see Figure 2.8).

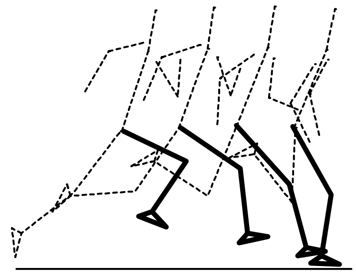


Figure 2.8. The late-swing phase.

The early stance phase starts at the instant of touchdown and continues for approximately half the stance phase (see Figure 2.9).

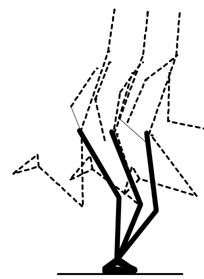


Figure 2.9. The early stance phase.

The late stance phase starts approximately halfway through stance and continues until the instant of takeoff (see Figure 2.10).

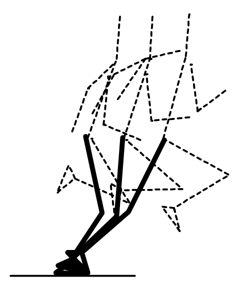


Figure 2.10. The late stance phase.

It is apparent that there are many phases of gait that make up the task of sprint running. Being aware of these phases gives one a sense of the complexity of sprint running as well as the many technical issues required for optimal sprint performance.

Biomechanics of Sprint Running

Once the athlete has left the starting blocks they are in the early acceleration phase of sprint running. The primary goal of the founding strides is to generate a rapid sprint running velocity. Horizontal sprint velocity is the product of the length and rate (frequency) of the athlete's strides or steps (Donati, 1996; Hay & Nohara, 1990; Hunter et al., 2004a) and can be observed in Figure 2.11.

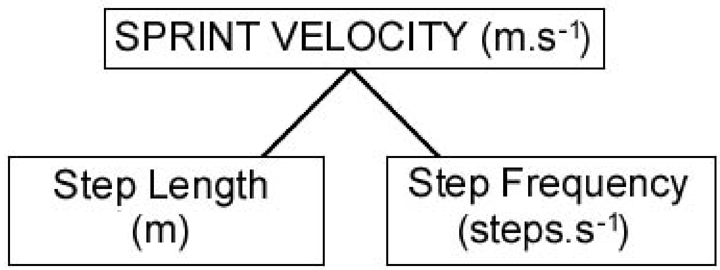


Figure 2.11. Determinants of sprint velocity

Step length can be measured as the horizontal distance the C.G. traveled during the step, or the horizontal distance between the two different foot contacts. Step frequency is the inverse of the duration of a step (the duration of a step being the time elapsed between consecutive touchdowns).

Hunter and colleagues (2004a) provided a deterministic model identifying the key components of step length and step frequency. Stance and flight time were the underlying determinants of step frequency, whereas stance and flight distance were the key indicators of step length (see Figure 2.12). It is possible that two athletes with the same horizontal velocity may employ different stride strategies, such as a high step frequency and low step length, or vice versa (Hunter et al., 2004a).

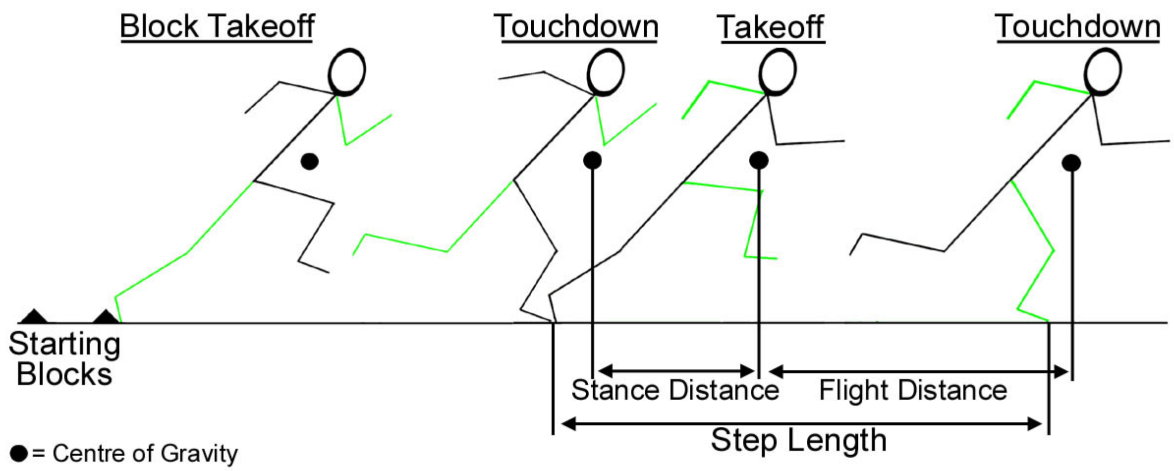


Figure 2.12. Components of step length (stance distance and flight distance).

When attempting to increase horizontal velocity an athlete can either increase their step length or their step frequency. An increase in one of these factors will result in an increase in sprint velocity, as long as the other factor does not undergo a proportionately similar or larger decrease referred to as “negative interaction” (Hunter et al., 2004a). The results of Hunter and colleagues (2004a) suggested that the vertical velocity at takeoff was the most prominent source of the negative interaction. The authors suggested that this vertical velocity at takeoff was largely determined by the vertical ground reaction impulse relative to body mass. A greater vertical velocity at takeoff can lead to an increased flight time, reduced step frequency and increase vertical oscillations of the C.G. (Mero et al., 1992; Mero, Luhtanen, Komi, & Susanka, 1988; Sprague & Mann, 1983). It has been proposed that most training effort should be placed on producing a high horizontal not vertical ground reaction impulse relative to body mass (Hunter et al., 2004a). Such a strategy would be advantageous for a long step length and high step frequency and hence a greater horizontal sprint velocity (Hunter et al., 2004a).

EMG Activity during Early Acceleration Sprinting

EMG has been used in various studies to measure muscle activity during sprinting. It has been reported that a 4.8% higher integrated EMG during stance occurs during the acceleration phase compared to the maximal velocity phase of sprinting (Mero & Peltola, 1989). It is thought that muscle involvement differs between the phases of acceleration and maximum velocity due to the more vertical position of the body in the maximal velocity than acceleration phase (Delecluse, 1997). Mann and colleagues (1986) investigated lower extremity EMG activity of 15 sprinters during the performance of three 100 m sprints in under 10 s. As speed increased EMG activity of the hip and knee joint muscles decreased during the support phase but increased during the swing phase. Greater muscle activity occurred during foot descent. These results are similar to the findings of Jonhagen and co-workers (1996) who found that the hamstrings showed a peak activity just prior to and during foot strike. It was concluded by the authors that the hamstrings work eccentrically to decelerate the thigh, and lower the leg during the swing phase. The results of Kyrolainen, Komi, and Belli (1999) also emphasised the importance of the hamstrings and hip extensors. The authors reported that the preactivity of these muscles to be a pre-requisite for both the enhancement of EMG activity during the braking phase and for timing of muscular action with respect to the ground contact. All these findings from the literature highlight the importance of the hip extensor musculature (hamstrings, gluteus maximus) in sprinting, and that this may become greater as speed increases.

Kinetics during Early Acceleration Sprinting

Muscular and elastic responses influence sprint performance. During the early acceleration phase the importance of muscle contraction is greater than elastic responses in the early acceleration phase (Delecluse, 1997). Kyrolainen, Komi, and Belli (1999) reported that in order for the running speed to increase so must force production particularly in the horizontal direction. The authors suggested that these horizontal ground reaction force (GRF) were primarily a result of the activity of the hip extensor muscles.

Ground Reaction Forces

During ground contact, a sprinter exerts with their foot, a force against the ground. According to Newton's third law of motion, an equal and opposite force is exerted by the ground against the foot (Hamill & Knutzen, 1995). A GRF is made up of three directional components: vertical, medial-lateral, and anterior-posterior (horizontal). The horizontal GRF components consist of a negative value (braking phase GRF) that occurs early in the stance phase posteriorly and a positive value (propulsion phase GRF) that occurs later in the stance phase anteriorly (Mero, Komi, and Gregor 1992).

Propulsive horizontal GRF's produced in the first ground contact after leaving the starting blocks have been reported to significantly correlate (r = 0.62 – 0.69) to the corresponding running velocity at the end of the first ground contact (Mero, 1988). Additionally, the optimal application of a propulsive horizontal GRF has been reported to increase the centre of gravity's velocity by 0.05 $m.s^{-1}$ and further improve 100 m performance by 0.06 – 0.08 s (Liu, Chen, & Chen, 2001). Bohn and co-workers (1998) reported that a faster athlete was able to produce a larger horizontal GRF (1.1 BW) and vertical GRF (3.6 BW) compared with an athlete of lesser ability (0.6 BW & 3.3 BW respectively). Mero (1988) reported insignificant correlations between vertical GRF's and running velocity at the end of the first ground contact after a block start. The differences between vertical force findings of Mero (1988) and Bohn and co-workers (1998) may be somewhat explained through the subject numbers or level of sprinters used in the studies.

It is unclear as to whether or not braking forces benefit sprint running performance due to the limited research in this particular area. However, Merni and colleagues (1992) have provided some insight into the area by reporting that the fastest athlete tested in their study had much higher braking forces than the other athletes tested. Maximal braking forces of 1.2 BW in the vertical direction and -0.7 BW in the horizontal have been reported (Merni et al., 1992).

The existing literature suggests that the propulsive horizontal GRF particularly is important to sprint running during the early acceleration phase. However more research is required examining the relationship between the vertical and braking GRF's on early acceleration sprint performance.

Ground Reaction Impulses

The ground reaction impulses (GRI) that occur during sprint running can occur in the vertical and horizontal directions. An insignificant correlation (r = 0.50) between vertical GRI produced during the first ground contact after a block start and the horizontal sprint velocity at the end of the first ground contact has been reported by Mero (1988). Hunter and colleagues (2004a) reported no change to horizontal sprint velocity due to a positive relationship between vertical GRI and step length and a negative relationship between vertical GRI and step frequency. Furthermore, vertical GRI is considered a major determinant of vertical velocity at takeoff a prominent source of negative interaction between step length and step frequency (Hunter et al., 2004a).

Horizontal GRI has been reported to significantly correlate (r = 0.71) with horizontal sprint velocity at the end of the first ground contact after a block start (Mero, 1988). Hunter and colleagues (2004a) proposed it was advantageous to direct training into the production of high horizontal not vertical GRI relative to body mass which would allow for an optimal combination of step length and step frequency and hence result in a greater sprint velocity.

Joint Moments & Power Outputs

During sprint running much of the mechanical power is transferred through the lower limb joints. Veloso and Abrantes (2000) investigated how much energy is transferred from the hip to the knee, and from the knee to the ankle during the second step from a block start. During the push-off phase the rectus femoris (thigh) muscle was reported to transfer approximately 34.5% of the net knee joint work from the hip to the knee. Furthermore, the energy transferred by the gastrocnemius (calf) from the knee to the ankle was 30% of the net ankle joint work. The authors concluded that these biarticular muscles are important for transferring energy from the proximal joints to the distal joints, thereby allowing a higher power output at the distal joint.

Joint moments, and joint powers have been examined by Johnson and Buckley (2001) through the hip, knee and ankle joint during the late swing, stance and early swing phases. Six subjects performed 35 m sprints on an indoor track, ground reaction forces were measured using a Kistler force platform 14 m from start line. Video images were also taken 17 m from the start line. It was reported by the authors that the joint peak moments during the late swing phase were hip extension (-275 Nm), and knee flexion (-135 Nm). During the stance phase the joint peak hip moments were 280 Nm during flexion and -377 Nm during extension. The knee experienced 269 Nm during knee extension of the stance phase. The peak joint powers reported by Johnson and Buckley (2001) during the late swing phase were -741 W during an eccentric hip extensor contraction, 2179 W during a concentric hip extensor contraction, and -2097 W during an eccentric knee flexor contraction. These results further identify the major role the hamstrings play during the swing phase, either through hip extension or knee flexion, and suggest that the hamstrings become eccentrically loaded during late swing. This has serious implications for physical conditioning.

Haneda and colleagues (2002) further highlighted the importance of the hamstring musculature acting eccentrically. The authors revealed an increase in hip and knee joint power relative to bodyweight during the recovery phase of sprinting gait, and suggested this increase was closely related to an increased stride length, stride frequency, and running velocity up to a distance of 20 m.

Kinematics during Early Acceleration Sprinting

Stance Time & Flight Time

A sprint cycle can be broken into stance time and flight time, where stance time is the time in which the individual is in contact with the ground and flight time is the time in which the individual is not in contact with the ground. Both stance time and flight time are common measures utilised in the sprint literature (Atwater, 1982; Lockie et al., 2003; Mero, 1988; Mero et al., 1983; Moravec et al., 1988; Murphy, Lockie, & Coutts, 2003). As sprint velocity increases, the proportion of total time spent in stance time tends to decrease while flight time increases (Moravec et al., 1988).

Stance times have been reported to range from 170 to 230 ms for the first ground contact (Atwater, 1982; Mero, 1988; Murphy et al., 2003), 150 to 190 ms for the second ground contact (Atwater, 1982; Mero, 1988; Murphy et al., 2003), and 124 to 125 ms at the 16 m mark (Hunter et al., 2004a). Stance times of the first and second contacts after a block start have been reported to both be correlated with the average velocity over 10 m ($r = -0.65$ & $r = -0.44$ respectively). Furthermore, stance times of 20 male field sport athletes during the first three steps of a 15 m sprint were reported to be significantly less for the faster than slower athletes (Murphy et al., 2003).

Flight times have been reported to range from 30 to 50 ms for the first step (Atwater, 1982; Mero, 1988; Murphy et al., 2003), 50 to 70 ms for the second step (Atwater, 1982; Mero, 1988; Murphy et al., 2003), and 102 to 121 ms at the 16 m mark (Hunter et al., 2004a). Hunter and colleagues (2004a) discovered using multiple regression that the C.G. height of takeoff (difference between the height of C.G. at takeoff and the height of the C.G. at the following touchdown) and the vertical velocity of takeoff were the key predictors of flight time.

Stance Distance & Flight Distance

Step length is the sum of the stance and flight distances (Hunter et al., 2004a). Stance distance is the distance the C.G. travels during the stance phase whereas flight distance is the distance the C.G. travels during the flight phase.

Athletes who employ a longer step length strategy have been shown to use significantly longer flight distances compared with athletes who employ a high step frequency to achieve the same horizontal sprint velocity (Hunter et al., 2004a). The key determinants of flight distance were the height of C.G. at takeoff ($r = 0.42$), vertical velocity of takeoff ($r = 0.65$), and horizontal velocity of takeoff ($r = 0.59$). Hunter and colleagues (2004a) found using multiple regression analysis that leg angle at touchdown, leg angle at takeoff, and leg length were the best predictors of stance distance. More research is required to quantify the optimal relationship between flight distance and sprint performance.

Lower Body Joint Kinematics

Mann and colleagues (1986) found that as the speed of gait increased, the range of and the velocity about the hip and knee increased considerably. The researchers further reported that at the hip joint, approximately 80° of motion occurred within 250 ms during sprinting, with the knee experiencing similar (65-70°) changes. These results illustrate that the angular displacement and velocity of the hip and knee joints are high during sprinting. Therefore, the muscles responsible for the initiation and control of these movements must act under extreme conditions.

Differences in sprinting standard may be partially explained by joint kinematic measures. Murphy, Lockie, and Coutts (2003) discovered that faster athletes had an 8% less knee angle at the take-off of the third step in comparison with slower athletes. The results of Murphy, Lockie, and Coutts (2003) suggested that in order to reduce stance time faster athletes may have abbreviated their knee extension at toe-off. The advantage of this strategy is that the reduced range of movement may allow for a more rapid turnover of the lower limbs during acceleration, which may lead to a faster sprint performance (Murphy et al., 2003).

Upper Body Joint & Segment Kinematics

Vigorous arm movements are considered a key element of sprinting (Korchemny, 1992). Hence, training to improve sprint acceleration involves a substantial technical emphasis on the actions of the upper limb (Lockie et al., 2003). When running, it is natural for the arms to rotate posteriorly and anteriorly, with the left arm in phase with the right lower-limb, and right arm in phase with the left lower-limb. At the most anterior point of the arm swing, the upper arm makes an angle of approximately 45° with the trunk, and at the rear-most position of the swing, the angle between the upper arm and trunk is approximately 80° (Mann, Kotmel, Herman, Johnson, & Schultz, 1984). Bhowmick and Bhattacharyya (1988) reported that the a faster arm swing increases the regulation of leg movement not the horizontal velocity of a sprinter. Hinrichs (1987) suggested that the arms provide the majority of the angular momentum needed to counteract the tendency for the angular momentum of the opposite leg to produce angular rotation in the transverse plane. A greater extension of the upper arm can cause a greater contribution of momentum from the upper body to occur that possibly results in a longer stride action (Bhowmick & Bhattacharyya, 1988).

During the first stance after leaving the blocks, the trunk has a pronounced lean, when viewed from the side. At each subsequent step the trunk becomes more upright. Data collected from eight male sprinters, revealed that the mean trunk-lean (measured from horizontal) at the moment of takeoff from the first, second, third, and fourth stance phases (from a block start) was 24°, 30°, 37°, and 44° respectively (Atwater, 1982). The trunk is also thought to play a major role in controlling the amount of rotation of the body about its transverse axis (Hay, 1993).

Anthropometrical, Strength, and Power Predictors of Sprint Performance

The ability to maximize sprinting speed requires not just good technique but also a favourable physical makeup. This part of the review will focus on the literature that has attempted to identify physiological, anthropometrical, strength, and power predictors of sprint performance.

Anthropometric and Physiological Predictors of Sprint Performance

It has been suggested that particular anthropometric measures are pre-requisites for good athletic performance in various sports (Kukolj et al., 1999).

However, few studies have attempted to predict sprint performance using anthropometrical and physiological measures in order for such a justification.

In a study conducted by Kukolj and co-workers (1999) anthropometric measures of lean body mass, percentage of muscle, and percentage of fat were calculated for twenty-four students competing in various sports. However, no significant relationships were observed between sprint performance (0 – 30 m) and any of these anthropometrical variables. Contrary to the findings of Kukolj and co-workers (1999) were those of Baker (1999). Sum of 8 skin folds of male rugby league players were revealed to be significantly related to their 10 m ($r = 0.81$) and 40 m ($r = 0.84$) sprint ability. Baker (1999) suggested that high levels of fat would have a negative effect on speed in rugby league players. Theoretically, this makes sense as an increase in velocity is proportional to the impulse generated by the athlete relative to their body mass. For the athlete with excess mass more force production would be required to achieve the same velocity as compared to a lighter athlete. Perhaps the differences in findings between Kukolj and co-workers (1999) and Baker (1999) were that Baker (1999) used a homogenous population (male rugby league players) compared to various sport athletes (Kukolj et al., 1999).

Height and leg length were also revealed to be a good predictors of acceleration phase velocity ($r = -0.64$ & $r = -0.56$ respectively). Linear regression analysis had revealed that leg length is a significant predictor of both stance distance and stance time at the 16 m mark of a short sprint (Hunter et al., 2004a). It is possible that the longer leg length would lead to an increased step length (via a longer stance distance) but it may have an adverse effect on step frequency due to a greater moment of inertia about the hip joint. Mero, Luhtanen and Komi (1983) reported significant correlations between early sprint velocities and various physiological measures of track sprinters. Fast twitch muscle fiber percentage of the vastus lateralis muscle was reported to have moderate correlations ($r = 0.59$ & $r = 0.62$) with block velocity and acceleration phase velocity respectively.

More information is required investigating the relationships between other anthropometrical dimensions and sprint performance. Perhaps dimensions such as hip width, femur or tibia length may yield stronger correlations or predictive strengths with sprint ability. Information from such an analysis would aid in the talent identification process.

Strength and Power Performance Predictors of Sprint Performance

Strength and power especially of the lower extremities may also determine sprinting performance. However the strength of this relationship may be affected by the mode of dynamometry (isometric, isokinetic or isoinertial) in which strength and power are assessed. An isometric contraction occurs when force is developed against an immovable object, so that no change in joint angle occurs (Abernethy, Wilson, & Logan, 1995). The term isokinetic is used to describe a muscle activity in which body movements occur at a constant velocity controlled by an dynamometer (Knuttgen & Kraemer, 1987). Isoinertial (constant gravitational load) assessment describes motion involving changes in tension, length and velocity whilst the load remains constant (Abernethy et al., 1995). Isoinertial assessment simulates movement patterns encountered in everyday function and sporting activity.

Isokinetic and isoinertial movement typically involve concentric and eccentric contractions (see Figure 2.13). A concentric contraction occurs as a muscle develops tension while it shortens. Whereas an eccentric contraction occurs when tension is developed as the muscle lengthens (Sale & MacDougall, 1981). A common human movement strategy is to couple the eccentric and concentric contractions into a sequence known as the stretch shorten cycle (SSC) (Enoka, 1996). A brief review of the predictive ability of isometric, isokinetic (concentric and eccentric) and isoinertial (concentric and eccentric) measures will follow.

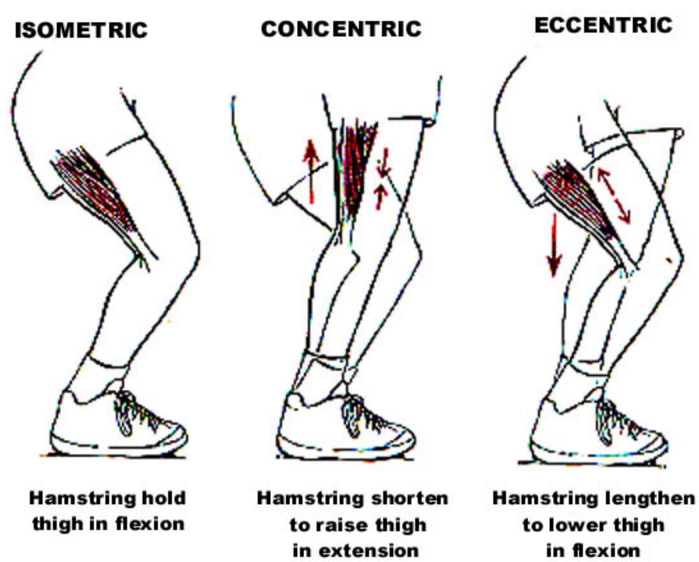


Figure 2.13. Muscle contractions (From Hamill & Knutzen (1995))

Isometric Measures

Few studies have attempted to predict sprint performance using isometric strength measures (Anderson et al., 1991; Kukolj et al., 1999; Mero et al., 1983). In fact it is still unclear as to the ability of these measures to predict sprint performance. Mero, Luhtanen and Komi (1983) reported significant correlations (r = 0.60 & r = 0.51) between block velocity and maximal isometric force of the knee extensor muscles expressed in absolute and relative (% of body mass) terms respectively. Absolute and relative maximal isometric force of the knee were also found to be good predictors of acceleration phase velocity, with relative isometric force (r = 0.60) being a better predictor than absolute isometric force (r = 0.46). Anderson and colleagues (1991) reported similar findings to that of Mero, Luhtanen and Komi (1983). Slightly lesser relationships (r = 0.40) were revealed between 40-yard (36.6 m) dash time and isometric force measures of the hamstring musculature (Anderson et al., 1991). Contrary to the findings of the two earlier studies mentioned are those of Kukolj and co-workers (1999) who reported very low insignificant correlations between sprint velocities of the early phases (0 – 30 m) and maximal isometric measures from the knee extensors, hip extensors and hip flexors. Possible reasons for the different findings amongst these studies could be the types of subjects used. Mero, Luhtanen and Komi (1983) used track sprinters, whereas Anderson and colleagues (1991) and Kukolj and co-workers (1999) assessed athletes in a variety of team sports. This suggests perhaps that isometric strength may be more related to sprinting performance in talented than novice sprinters and that the relationship may be higher at the quadriceps muscle than that of the hamstrings or hip flexors.

The literature suggests isometric force output from the lower limb musculature may be of moderate to low importance during the early phases of sprint running. This is surprising as sprint running is a dynamic action with no requirement of isometric activity from the lower limb musculature. Therefore it is unclear as to whether testing the maximal isometric force production capabilities of sprinters is able to predict sprint performance. Differences in the muscle group assessed, the type of subjects used, and a lack of specificity of this type of measure (static) to that of sprint running (dynamic) could potentially contribute to discrepancies associated with these isometric measures.

Isokinetic Tests

Devices such as the Cybex, Biodex and Kin-Com systems are commercially available for the assessment of isokinetic strength (Abernethy et al., 1995). Many researchers have used isokinetic dynamometry to measure force and power and relate these measures to sprint performance (Alexander, 1989; Anderson et al., 1991; Dowson, Nevill, Lakomy, Nevill, & Hazeldine, 1998; Liebermann & Katz, 2003; Manou, Saraslanidis, Zafeiridis, & Kellis, 2003). These studies have typically reported mainly moderate relationships between isokinetic measures and sprint performance. However, the application of these findings to sporting activity is thought questionable due to a lack of external validity (Cronin, McNair, & Marshall, 2002). This is the fact that normal human movement involves accelerations and decelerations and is generally the result of the activation of various muscle groups. Most isokinetic dynamometers velocities are unable to reach the actual velocities that muscles contract at during sport activities and only assess single joint tasks. In contrast, isokinetics are conducted with virtually no acceleration and have traditionally involved single-joint actions, Nonetheless, isokinetic measures and their relationships with sprint performance will be reviewed briefly. This will be done for concentric and eccentric measures.

Eccentric Measures

Few studies have examined whether eccentric isokinetic strength measures are predictors of sprint performance (Alexander, 1989; Anderson et al., 1991; Dowson et al., 1998; Manou et al., 2003; Nesser et al., 1996). It can be observed in Table 2.2 that isokinetic eccentric strength measures are generally only weakly correlated ($r = < -0.43$) with acceleration performance (0 - 15 m). However, eccentric strength appears to be more important as the distance is increased. It is not surprising that eccentric strength is not crucial during the acceleration phase as this phase is characterised by a strong concentric component (Mero & Komi, 1986; Mero et al., 1992; Mero et al., 1983).

Table 2.2. Relationships between isokinetic eccentric strength measures and sprint performance.

Reference	Subjects	Eccentric strength measure	Performance	Correlation
Alexander (1989)	14M 9F SP	M: Dorsi P_{Torque} @ 30°/s	100m (s)	-0.53*
Anderson et al. (1991)	39M TSA	R hamstring P_{Torque} @ 30°/s	36.6m (s)	0.43**
		R hamstring A_{Torque} @ 30°/s	36.6m (s)	0.44**
Dowson et al. (1998)	24M TSA	Kext P_{Torque} @ 60°/s	0 – 15m (s)	-0.43*
		Kext P_{Torque} RBM @ 60°/s	0 – 15m (s)	-0.41*
		Kext P_{Torque} @ 60°/s	30 – 35m (s)	-0.50**
		Kext P_{Torque} RBM @ 240°/s	30 – 35m (s)	-0.47*

Abbreviations: * = p<0.05; ** = p<0.01; M = male; F = female; SP = sprinters; TSA = team sport athletes; Dorsi= dorsiflexion; P_{Torque} = peak torque; R = right; A_{Torque} = average torque; Kext = knee extension; RBM = relative to body mass

Concentric Measures

A number of studies have investigated the relationship between concentric isokinetic strength measures and sprint performance (Alexander, 1989; Anderson et al., 1991; Dowson et al., 1998; Manou et al., 2003; Nesser et al., 1996). Table 2.3 reveals that as the sprint distance increases concentric isokinetic strength measures increase in their ability to predict sprint performance (Alexander, 1989; Anderson et al., 1991; Dowson et al., 1998; Manou et al., 2003; Nesser et al., 1996). For the acceleration phase correlations ranged from r = -0.42 to -0.58 for knee extension, knee flexion and plantar flexion torque measures at speeds ranging from 120°/s to 240°/s. According to Dowson and colleagues (1998) the relationship between isokinetic strength and sprinting speed increased as the velocity of contraction increased. Also, when the strength measures were expressed relative to body mass the strength of the relationship also increased (Dowson et al., 1998). It is not surprising that force measures relative to body mass are better predictors of sprint performance than absolute measures, as this type of measure is more specific to sprint running, due to the need to produce high levels of force relative to body mass in order to propel the body forward.

Table 2.3. Relationships between isokinetic concentric strength measures and sprint performance.

Reference	Subject	Concentric strength measure	Performance	Correlation
Alexander (1989)	14M 9F SP	M: Kext P_{Torque} @ 230°/s	100m (s)	-0.71**
		F: Dorsi P_{Torque} @ 30°/s	100m (s)	-0.77*
Anderson et al. (1991)	39M TSA	R hamstring P_{Torque} @ 60°/s	36.6m (s)	0.57**
		R hamstring A_{Torque} @ 60°/s	36.6m (s)	0.55**
Dowson et al. (1998)	24M TSA	Kext P_{Torque} @ 150°/s	0 – 15m (s)	-0.42*
		Kext P_{Torque} @ 240°/s	0 – 15m (s)	-0.52**
		Kflex P_{Torque} @ 150°/s	0 – 15m (s)	-0.47*
		Kflex P_{Torque} @ 240°/s	0 – 15m (s)	-0.51*
		Kext P_{Torque} RBM @ 150°/s	0 – 15m (s)	-0.44*
		Kext P_{Torque} RBM @ 240°/s	0 – 15m (s)	-0.58**
		Kflex P_{Torque} RBM @ 150°/s	0 – 15m (s)	-0.53**
		Kflex P_{Torque} RBM @ 240°/s	0 – 15m (s)	-0.56**
		Kext P_{Torque} @ 60°/s	30 – 35m (s)	-0.49*
		Kext P_{Torque} @ 150°/s	30 – 35m (s)	-0.64**
		Kext P_{Torque} @ 240°/s	30 – 35m (s)	-0.69**
		Kflex P_{Torque} @ 60°/s	30 – 35m (s)	-0.53**
		Kflex P_{Torque} @ 150°/s	30 – 35m (s)	-0.64**
		Kflex P_{Torque} @ 240°/s	30 – 35m (s)	-0.67**
		Hext P_{Torque} @ 120°/s	30 – 35m (s)	-0.43*
		Hext P_{Torque} @ 180°/s	30 – 35m (s)	-0.46*
		Kext P_{Torque} RBM @ 150°/s	30 – 35m (s)	-0.58**
		Kext P_{Torque} RBM @ 240°/s	30 – 35m (s)	-0.66**
		Kflex P_{Torque} RBM @ 60°/s	30 – 35m (s)	-0.46*
		Kflex P_{Torque} RBM @ 150°/s	30 – 35m (s)	-0.63**
		Kflex P_{Torque} RBM @ 240°/s	30 – 35m (s)	-0.65**
		Hflex P_{Torque} RBM @ 60°/s	30 – 35m (s)	-0.57**
Manou et al. (2003)	18M 8F SP	Sitting Kext P_{Torque} @ 30°/s	30m (s)	-0.59*
		Sitting Kext P_{Torque} @ 300°/s	30m (s)	-0.52*
		Prone Kext P_{Torque} @ 30°/s	30m (s)	-0.59*
		Sitting Kflex P_{Torque} @ 30°/s	30m (s)	-0.60*
		Prone Kflex P_{Torque} @ 30°/s	30m (s)	-0.53*
Nesser et al. (1996)	20M TSA	Hflex P_{Torque} @ 180°/s	40m (s)	-0.57*
		Hext P_{Torque} @ 450°/s	40m (s)	-0.54*
		Kflex P_{Torque} @ 180°/s	40m (s)	-0.56*
		Kflex P_{Torque} @ 450°/s	40m (s)	-0.61*
		Kext P_{Torque} @ 450°/s	40m(s)	-0.55*

Abbreviations: * = p<0.05; ** = p<0.01; M = male; F = female; SP = sprinters; TSA = team sport athletes; Kext = knee extension; P_{Torque} = peak torque; Dorsi = dorsiflexion; R = right; A_{Torque} = average torque; RBM = relative to body mass; Kflex = knee flexion; Hext = hip extension; Hflex = hip flexion

Isoinertial Tests

A variety of isoinertial assessments have been used to predict sprinting performance. Strength is most commonly assessed by the maximum weight that can be lifted for one or three repetitions. These strength measures are commonly called the 1RM or 3RM, respectively. Muscular power is generally indirectly assessed by jumping ability, especially as assessed in the squat jump, counter movement jump, drop jump, and vertical jump. Some of these jump assessments will be reviewed in the context of concentric and SSC measures in the following paragraphs.

Concentric Measures

The squat jump (SJ) is considered a measure of leg explosiveness under concentric conditions (Young, 1995). In such an assessment the athlete starts in a bent knee position (approximately 120^{o} knee angle) with their hands on their hips . The athlete will hold this position for approximately four seconds and then attempt to jump as high as possible without any countermovement (see Figure 2.14).

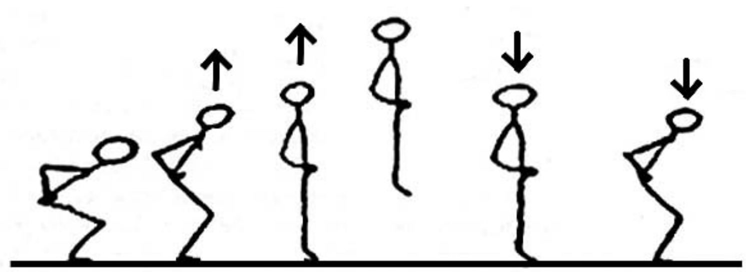


Figure 2.14. Squat jump sequence (N.B. the jump is straight up, not forwards).

The relationship between SJ and sprinting performance has been assessed in many studies (Mero et al., 1983; Morin & Belli, 2003; Young et al., 1995). In the first few steps of sprint running, the propulsion (concentric action) has been reported to be 81.1% of the total step duration whereas this reduces to 57% during the maximal velocity phase (Mero, 1988). This therefore suggests that the generation of high levels of concentric power is especially important in the very early phases of sprint running. Therefore it is no surprise that the correlation between SJ and sprinting performance over distances up to 40 m is typically high (r = 0.63 – 0.86) (Mero et al., 1983; Morin & Belli, 2003; Young et al., 1995). Mero, Luhtanen and Komi (1983) revealed male sprinters (100 m Personal best: 10.2 – 11.8 s) who possessed greater SJ ability generated greater block velocity and velocity attained over 10 m, with correlations of r = 0.63 and r = 0.68 respectively being reported. In accordance to the findings of Mero, Luhtanen and Komi (1983) were those of Morin & Belli (2003) whom studied the mechanical muscular parameters linked with the performance of different phases of a 100 m sprint. Ten trained male sprinters with a mean 100 m personal best of 11.3 ± 0.3s were recruited for this study. Significant correlations ranging from r = 0.66 – 0.69 were reported between SJ performance and acceleration phase (10 – 40 m) velocity. Kinetic variables were measured by Young, McLean, & Ardagna (1995). The researchers discovered peak force relative to bodyweight from a loaded SJ performed from a 120° knee angle to be the single best predictor (r = 0.86) of starting performance (time to 2.5 m).

All these findings suggest that the SJ is a good predictor of acceleration performance and may be a useful training strategy to improve performance in the acceleration phase. Bret and colleagues (2002) reported that concentric strength is not only important during the acceleration phase but also the maximal velocity and deceleration phases. The study revealed the force produced during loaded half-squats was correlated to performance in the 0 to 30m acceleration phase (r = 0.61), the 30 – 60 m maximal velocity phase (r = 0.68), and the 60 – 100 m deceleration phase (r = 0.68).

The force produced or the height obtained during concentric jump tests appear to be very good predictors of sprint performance. The inclusion of training strategies that emphasise concentric strength or power may be advantageous in the improvement of all phases of sprint performance.

SSC Strength Measures

Baker and Nance (1999) examined the relationships between lower body strength and sprint performance of twenty professional rugby league players. Strength was assessed by determining the 3 RM loads for the full squat and hang clean and sprint performance by the 10 m and 40 m sprint times. Absolute measures of strength in both exercises expressed non significant relationships (r = -0.06 & r = -0.36 for squat and power clean respectively) with both 10 m and 40 m sprint times. However, when the strength measures were expressed relative to body mass significant relationships occurred between the strength measures and sprint performances. Specifically, a relationship of r = -0.66 was reported between the 3 RM squat and 40 m sprint time. The 3 RM power clean expressed relationships with both 10 m and 40 m sprint times with reported correlations of r = -0.56 and r = -0.72 respectively. This further highlights the importance of sprinters having a high level of relative SSC strength and power.

SSC Jump Measures

Young (1995) considers the countermovement jump (CMJ) a test of SSC ability. The CMJ assessment requires an athlete to start with their hands on their hips, they are then instructed to sink as quickly as achievable and then jump as high as possible in the ensuing concentric phase (see Figure 2.15).

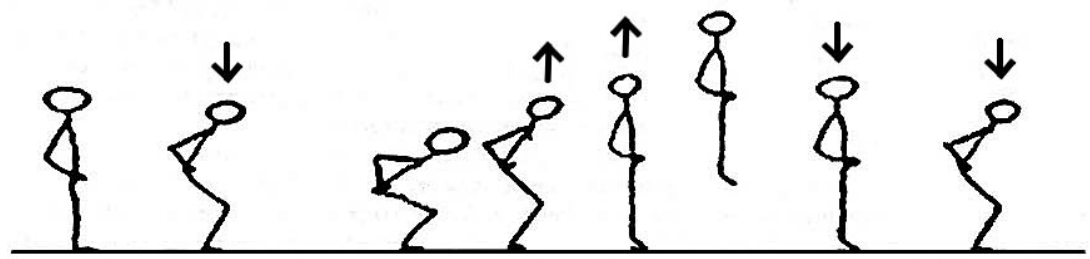


Figure 2.15. Countermovement jump sequence (N.B. the jump is straight up, not forwards).

It can be observed in Table 2.4 that the CMJ and sprint performance are highly correlated (Bret et al., 2002; Kukolj et al., 1999; Liebermann & Katz, 2003; Mero et al., 1983; Young et al., 1995). In particular the CMJ appears to be crucial to acceleration performance. Mero, Luhtanen, and Komi (1983) reported significant relationships between CMJ height and block leaving velocity and the average velocity to 10 m (r = 0.69 & r = 0.70 respectively) for male track sprinters. Similar relationships have been reported for other studies involving high level sprinters (Bret et al., 2002; Young, 1995). Contrary to this were the findings of Kukolj and associates (1999) who discovered no significant relationship between CMJ height and average velocity to 15 m for male athletes from various field sports. This suggests that perhaps SSC ability is more mandatory for track sprinters than athletes from various field sports in the early phases of a sprint, or perhaps that track sprinters are better able to utilise the muscle pre-stretch due to the types of training they perform.

Due to the strong relationships overall with sprint performance the CMJ should be considered as a training exercise to enhance sprint performance especially during the acceleration phase.

Table 2.4. Relationships between countermovement jump measures and sprint performance.

Reference	Subjects	Performance	Correlation
Mero et al., 1983	25 M SP	Block velocity ($m.s^{-1}$) Acceleration phase velocity ($m.s^{-1}$)	0.69** 0.70**
Young et al., 1995	11 M 9 F T & F	Maximum sprinting speed (fastest 10m portion time (s))	-0.77**
Kukolj et al., 1999	24 M TSA	0.5 to 15m average velocity ($m.s^{-1}$) 15 to 30m average velocity ($m.s^{-1}$)	0.09 0.48*
Bret et al., 2002	19 M SP	0 to 30m average velocity ($m.s^{-1}$) 30 to 60m average velocity ($m.s^{-1}$) 60 to 100m average velocity ($m.s^{-1}$)	0.66* 0.53* 0.44*
Liebermann et al., 2003	14 M 6 F TSA	0 to 20m sprint time (s)	-0.88**

Abbreviations: * = p<0.05; ** = p<0.01; M = male; F = female; SP = sprinters; T & F = track and field athletes; TSA = team sport athletes

While SSC jumping assessments are traditionally done vertically, there is no reason why they can not also be performed in the horizontal direction. Intuitively it would seem that horizontal jump assessment, which involves both vertical and horizontal propulsive forces, would better predict those activities that involve horizontal motion such as sprinting. However, very few studies have used horizontal jump assessment to predict sprinting performance. Nesser and colleagues (1996) using a 5-step horizontal jump reported a strong relationship (r = -0.81) between distance jumped and 40 m sprint performance. During the 5-step jump rapid stretching and high velocity contractions of the lower extremity occur (Nesser et al., 1996), which is very similar to that which occurs during sprinting. However, Mero and co-workers (Mero et al., 1983) reported a lower relationship (r = 0.66) between the triple hop for distance and acceleration phase (10 m) velocity. This difference could most probably be attributed to the contention that the beginning phases of a sprint are predominantly concentric or slow SSC in nature. Therefore a test such as the triple hop for distance may be more relevant to the maximum speed than acceleration phase.

Jump Height vs. Jump Power

The majority of research that has examined the relationships between jumping power and sprint ability have quantified jump performance by the distance obtained in the vertical or horizontal jump. These studies have reported correlations between these measures between r = 0.44 – 0.77 (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983; Nesser et al., 1996). However, Bradshaw and Le Rossignol (2004) reported that the use of vertical height measures to gauge performance level in gymnasts was inadequate. In fact, of the few studies which have used more sensitive measures such as force and power developed during the jump task; all have reported stronger correlations with sprint performance. For example, Liebermann and Katz (2003) reported a very strong correlation between the mean peak power during a countermovement jump (CMJ) and 20 m sprint time (r = -0.88) whereas other researchers have reported correlations ranging between r = 0.44 – 0.70 for CMJ jump height ability and sprint velocity of the acceleration phase (0 to 30m) (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983), and maximum sprinting speed (r = -0.77) (Young et al., 1995). Young, McLean and Ardagna (1995) also observed a strong relationship between the maximum force developed during a weighted squat jump (SJ) and sprint time to 2.5 m (r = -0.86). Therefore, identifying the predictive ability of more sensitive kinetic measures with sprint performance from various types of jump assessments warrants further research.

Stiffness Measures

Lower extremity stiffness is considered to be a critical factor in musculoskeletal performance (Butler, Crowell III, & McClay Davis, 2003). Stiffness can be defined as the amount of deformation experienced by a body per unit force (Butler et al., 2003), and has been suggested to be very important in stretch shorten cycle exercises (Komi, 1986). It is possible that different types of athletes differ in level of stiffness with vertical leg stiffness being reported to be significantly higher in sprinters compared with endurance runners (Harrison, Keane, & Coglan, 2004). The physiological determinants of active stiffness are the contributions from the muscular component, length-feedback component (muscle spindles) and force-feedback-component (Golgi tendon organ) (Komi, 1986). Butler and colleagues (2003) suggest stiffness to be related to both performance and injury, as some stiffness may be necessary for performance, but too much or too little stiffness may possibly lead to injury.

Muscle stiffness of the leg and its relationship to sprint performance has recently been shown to be moderately high (r = 0.66 - 0.68) (Bret et al., 2002; Chelly & Denis, 2001; Morin & Belli, 2003). This offers considerable support for the view that leg stiffness is related to the maximal velocity phase of sprint running. Chelly and Denis (2001) found a correlation of r = 0.68 between leg stiffness (as measured from a 10 s hopping test) and 40 m running velocity of 11 male handball players. The authors suggested leg stiffness calculated from hopping is a good indicator of the power absorbed and then restituted during the successive eccentric and concentric phases of the leg impulses (reactive power). Bret and colleagues (2002) also reported a moderately high relationship (r = 0.66) between leg stiffness measured from 10 s of continuous straight legged jumps and the velocity attained during the 30 – 60 m portion of a 100 m race in 19 junior and senior male sprinters. Morin and Belli (2003) tested ten male sprinters and found leg stiffness measured from 15 s of repeated jumps to be a good predictor (r = -0.68) of time to 90% maximal velocity of a 100 m sprint. All these findings suggest that having a stiffer musculotendinous unit is advantageous to the maximal velocity sprint phase. A stiff musculotendinous unit has been speculated to enhance the rapid transmission of force (Komi, 1986). During the maximal velocity phase ground contact times are very short (~ 100 ms), and maximal force production is required to maintain a high running velocity in this short time (Chelly & Denis, 2001; Mero et al., 1992).

Alternatively, Chelly and Denis (2001), Bret and colleagues (2002), and Morin and Belli (2003) have found little relationship between leg stiffness and acceleration phase sprint performance. This may be attributed to the need for forward power, less reactive power, low muscle contraction velocity and longer ground contact times associated with acceleration phase sprinting (Bret et al., 2002; Chelly & Denis, 2001).

Training Strategies for Sprint Performance

Sprint coaches use a variety of training methods to improve the performance of their sprinters (Saraslanidis, 2000). These may include standard sprint training, resistance training, jump training, flexibility training and more sprint specific methods such as resisted and assisted sprinting. This part of the review will focus on the specificity considerations of training, longitudinal strength and power training literature and particularly that of resisted sprint training.

Specificity of Training

The application of strength and power to athletic performance usually occur under conditions delimited by posture, velocity, contraction type, and contraction force (Harman, 1993; Komi, 1992; Sale & MacDougall, 1981). Therefore these variables must be considered when developing training strategies. Training methods need to be specific to the activity in order to maximize the transfer to functional performance (Sale & MacDougall, 1981) . Periodisation is used throughout an athletes training regime to promote long term training and performance improvements (Baechle & Earle, 2000). It is commonly believed that as the proportion of specific training should increase as the athlete goes from the off-season to in-season phases of their annual periodised training programs.

Wilson, Murphy, and Walshe (1996) reported that activities which were performed in a similar posture to that of strength training tend to improve to the greatest extent, compared to those performed in dissimilar postures. This was partly due to the differing postures affecting direction of the force application of the musculature, thereby altering its neural input. Additionally, the role of stabilizer muscles was altered as a result of the different postures adopted. This suggests that training exercises should be posture specific to that of the movement in order for the appropriate neural stimulus to be achieved.

Velocity specificity suggests that to maximize the transfer of training to functional performance that the velocity of the training exercises should be similar to that of the sporting activity. Sale and MacDougall (1981) suggested that strength training programmes designed for “speed” and “power” athletes should include fast movements to train the muscles to move both quickly and forcefully. However, the notion of velocity specificity has been recently challenged in a review by Cronin, McNair, and Marshall (2002). The authors suggested that developing qualities such as strength, power, and rate of force development (with heavier loads) would be of greater importance than training at the actual movement velocity of the sporting activity. Cronin, McNair, and Marshall (2002) also discussed the fact that all training exercises are slower than that seen in most sporting activities.

The maximal force a muscle can exert at optimal length depends on its speed of contraction (Herzog, 1996). The force-velocity relationship describes the momentary condition of the neuromuscular system for the production of force at different contraction velocities (Viitasalo, 1985). During concentric (shortening) contractions the force decreases as the speed of contraction increases, where as for eccentric (lengthening) contractions the force increases with increasing speeds (Herzog, 1996) (see Figure 2.16).

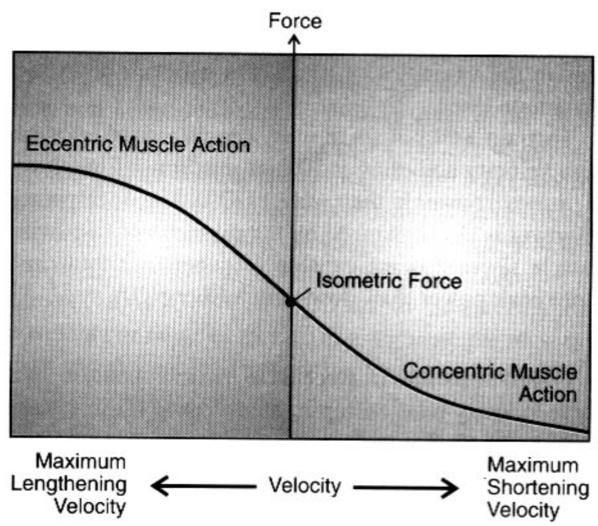


Figure 2.16. Force velocity relationship. (From Hamill & Knutzen (1995)).

Sale and MacDougall (1981) stated that training should generally consist of the same contraction type that is used in competition if the appropriate neural adaptations are to occur. For example, it would not be advantageous for an athlete in an event that requires predominantly concentric activity to perform training heavily of stretch shorten cycle nature or vice versa.

Contraction force specificity involves the selection of training loads that are of the same relative intensity of muscle contractions that occur during the sporting task (Sale & MacDougall, 1981). As muscular power may be more important than muscular strength for most activities, it is also important to select contraction forces that allow for the maximisation of muscle power. Muscular power may be maximized when using loads of 30-60% 1RM in activities such as jump squats and bench press throws (Baker, Nance, & Moore, 2001; Cronin, McNair, & Marshall, 2000; Wilson, Newton, Murphy, & Humphries, 1993). Therefore, Keogh and associates (1999) have suggested that a range of loads can be used in training to improve athletic performance, although in keeping with the principles of contraction and velocity specificity, an attempt should be made to simulate the force and velocity characteristics of the movements relevant to each sport. As an example, Keogh and associates (1999) suggested that a high jumper would use a lower percentage of 1RM for squat jumps than a weight lifter because of the differing demands of these sports.

In light of all these training specificity variables there is much to consider when developing training programmes for athletes. It is apparent from the literature that training strategies should be specific to the sporting task. Through utilising specific training strategies one can be certain that the appropriate adaptation will occur and more likely transfer to an improvement in sporting performance

Strength and Power Training Methods

One of the first studies to assess the effect of alternative (strength and flexibility) training approaches to sprinting performance was conducted by Dintiman (1964). Changes in 50 yard (45.72 m) sprint, flexibility and leg strength were assessed after an 8-week training program that involved three training sessions a week. The participants (n = 145) were randomly allocated to one of five groups: flexibility and sprint training; weight training and sprint training; flexibility, weight training and sprint training; sprint training; control group. It was revealed that combining sprint training with either flexibility or weight training did not improve running speed significantly more than sprint training only. However when both flexibility and weight training were combined with sprint training, superior improvements were achieved in sprint performance compared to that of sprint only training.

Delecluse and colleagues (1995) has assessed the effects of high resistance (weight training) and high velocity (unloaded plyometric) training on different phases of 100 m sprint performance. Subjects were assigned to one of four groups consisting of two training groups and two control groups. The weight training and plyometric training groups performed exercises for all main muscle groups of the upper and lower body twice a week for nine weeks. In addition both training groups participated together in a sprint running workout once a week. The two control groups were a sprint control group who participated in the sprint running workout with the two training groups, and a passive control group who did no prescribed training. The high velocity group improved significantly more in the initial acceleration phase (0-10 m) than the other groups. Furthermore, compared to the two control groups the high velocity group also improved significantly in total 100 m time. High resistance training also resulted in an improved initial acceleration phase, but no more than sprint training alone. It was concluded by Delecluse and colleagues (1995) that for achieving gains in sprint performance velocity specificity and movement specificity are of paramount importance. However, as the sprinters used a standing start, the results of Delecluse and colleagues (1995) may not be applicable to track sprinters. Further examination of the effects that high resistance and high velocity training procedures may have on sprint start performance is needed in order to gain a better appreciation of such training methods.

Rimmer and Sleivert (2000) also examined the effect of plyometric training on sprint performance. Thirty two males competing in various team sports were randomly allocated into one of three groups: plyometric (high velocity), standard sprint, and control. It was discovered from the study that an eight week training program of sprint specific plyometric exercises improved sprint performance up to 40 m in length. However the improvements in 40 m time were no greater than those obtained from standard sprint only training. Sprint kinematics during the sprint performance was also measured pre and post training. No changes in stride length were detected in either training group, with the only change in stride frequency being a decrease over the 0 - 10 m interval for the sprint group. Decreases in contact time at the 37 m mark of the 40 m sprint were discovered for the plyometric group.

Blazevich and Jenkins (2002) have assessed the effects of either a high velocity or low velocity weight training program on sprint performance. Both training groups performed the same lower body exercises i.e. the squat, hip flexion and extension, and knee flexion and extension. The high velocity group performed these exercises with loads of 30 – 50% 1 RM, while the low velocity group used loads between 70 - 90% 1 RM Both groups significantly improved their 20 m sprint time, although the magnitude of this improvement was not significantly different between the two weight training groups.

The results of this literature suggest that resistance-training can improve sprinting performance. However, the optimal prescription of such training approach is not well understood at present. This may allow the coach or a physical conditioner to utilise an arsenal of training techniques throughout their athlete's long term training plan (1 – 4 years). This will keep training interesting and possibly fun for the athlete. However, the athlete must be monitored and assessed during the training intervention in order to ensure the appropriate training goal is being stimulated accordingly.

Resisted Sprinting

Resisted sprint training is a normal component of many sprinters training programs. This may potentially involve weighted vest running, uphill running, resisted towing, sand and water running (Faccioni, 1994). The suggested benefits from using these training methods are an increased stride length (Delecluse, 1997), an increase in muscular force output of the lower body (Saraslanidis, 2000), and the development of specific recruitment patterns that target the fast-twitch muscle fibers (Lockie et al., 2003).

It would appear that the most popular resisted running technique is that of resisted towing. This type of training can involve the towing of a sled, tyre, speed chute (parachute), or other weighted device (Faccioni, 1994). Resisted sled towing is the more common training method utilised to improve aspects of the acceleration phase and has been suggested as the most appropriate training technique to improve the strength of the muscles that contribute to sprinting (Saraslanidis, 2000). A resisted sled device can be observed in Figure 2.17. Whilst resisted sled towing is a popular method for training acceleration performance in sprinters and field sport athletes, the effects of resisted sled towing has not yet been adequately quantified and is therefore not well understood. Specifically, little is known on what the best loads are required to induce maximal gains without changing sprint technique dramatically. Also, insufficient evidence exists on what aspects of sprinting performance are actually improved by this form of training.

Figure 2.17. A resisted sled device

Loading Strategies

Due to the paucity of resisted sled towing research it is still unclear as to what effect different loads have on the acute sprinting kinematics and which loads are the most appropriate to induce a significant training effect. The level of resistance imposed on the sprinter can be expressed as an absolute load (e.g. 5kg) or relative to the individual's body mass (e.g. 5% body mass). The coaching and physical training literature advocates that absolute loading schemes (e.g. 5 kg) should be employed during resisted sled tow training (Letzelter et al., 1995; Mouchbahani et al., 2004; Saraslanidis, 2000). The limitation of prescribing absolute loads as a guideline for coaches, is that the athletes individual anthropometry (e.g. stature and mass), physical strength, and current sprint performance capabilities are not considered. Resisted sled towing with a 10 kg load may be an appropriate stimulus for one athlete but be excessive for another. Guidelines that recommend loads relative to body mass may be more appropriate, as these loads can be more adequately generalized to athletes of various sprinting ability, body mass and lower body strength.

Mouchbahani and associates (2004) suggested the use of a 5 - 10% body mass load when performing resisted towing. Lockie, Murphy, and Spinks (2003) suggested that a 12.6% body mass load was required to enhance hip flexion during the leg drive phase, resulting in improvements to the length and rate of the strides but with minimal disruption to technique. However Lockie et al. (2003) contended that a load of 32.2% body mass was better for developing the upper body action during accelerative sprinting. Although these guidelines offer some insight into loading schemes to employ for certain technical aspects of sprint running, it is still unclear as to the appropriate magnitude of the loads to utilise. It may be that loads other than those suggested by Lockie, Murphy, and Spinks (2003), and Mouchbahani and associates (2004) are more appropriate at stimulating technical aspects of sprint running. Additionally, certain loads may be more appropriate for sprints performed from a block start compared to a standing start.

The Effects of Resisted Sled Towing on Sprint Technique

Past research has revealed that resisted sled towing causes acute alterations in sprint kinematics of the acceleration phase (Letzelter et al., 1995; Lockie et al., 2003). Letzelter, Sauerwein, and Burger (1995) tested 16 trained female sprinters (100 m = 12.5 s) who performed 30 m sprints unresisted and with sled loads of 2.5 kg, and 10 kg. Sprint performance was decreased by 8% and 22% respectively for the loads of 2.5 kg and 10 kg. The results indicated that the loss of sprinting speed with increased load was predominantly a result of a reduction in stride length. Decreases in stride length of 5.3% and 13.5% respectively for the 2.5 kg and 10 kg loads were reported. Stride frequency only decreased by 2.4% with a 2.5 kg load and 6.2% with a 10 kg load. Increases in stance time, trunk lean and hip flexion angle were also revealed across all loads. Similar findings were reported by Lockie, Murphy and Spinks (2003) for 20 males athletes who participated in various field sports. The participants performed sprints over 15 m under three different loading conditions of no resistance and with a sled loaded with either a 12.6% or 32.2% body mass load. These loads were used as they caused a decrease in 10% and 20% of maximum 15 m velocity respectively. Decreases in stride length of 10% and 24% respectively for each load were reported. Stride frequency was revealed to only decrease slightly (6% for both loads). Also stance time, trunk and hip angle were reported to increase with sled towing, which is in accordance with Letzelter, Sauerwein, and Burger (1995). Furthermore, Lockie, Murphy and Spinks (2003) discovered as load increased shoulder range of motion also increased. The authors suggested the load of 12.6% body mass to be the better training load to use as it does not cause too much disruption in sprint kinematics such as stride length, stride frequency, and hip flexion.

Saraslanidis (2000) conducted a training study comparing resisted sled towing and unresisted sprint running to identify which method was best in enhancing maximum speed. Forty five male university students whom participated in various sporting pursuits were divided into two training groups of 15 participants each, and a control group of 15 participants. One of the training groups performed unresisted sprint running only, whereas the other training group performed resisted sprint running with a 5 kg sled. The subjects in the two training groups trained three times a week for eight weeks, with each training session consisting of four 50 m sprints at 100% effort. Two maximal sprints over 50 m were performed pre and post training to assess the effect of the different training interventions. The best sprint was then split into three sections for analysis 20 – 40 m, 40 – 50 m and 20 – 50 m. Saraslanidis (2000) found that resisted sled towing did not improve performance in the maximal velocity phase (20 - 50 m) and even decreased performance between 40 – 50 m . It was suggested by Saraslanidis (2000) that due to the sprinting action during resisted sled towing being more of a concentric than eccentric action, the eccentric contribution to the respective SSC was reduced, thereby negatively affecting the maximal velocity phase. No kinetic or kinematic variables were measured, which perhaps may have given a better idea as to why performance did not change. However the findings of Saraslanidis (2000) suggest that resisted sled towing with a 5 kg mass is not appropriate for altering maximum velocity phase performance.

Further longitudinal research investigating the alterations in sprint performance and sprint mechanics of the early sprint phases are needed to provide insights to the potential benefits of resisted sled towing. The identification of the kinematic alterations to sprint start technique that result from resisted sled loading, if any, would provide informative information on how this training tool can be used to improve sprint start performance.

Pre-requisites for Minimal Technique Disruption

When prescribing resisted sled loading, coaches would be aware of whether the individuals sprint technique is being positively or negatively altered by the additional resistance. The amount of technique disruption that is acceptable when training a sprinter with an added load has not been widely debated. Jakalski (1998), for example, suggests that athletes should not be slowed down more than 10%, due to the changes in ground contact dynamics. Further, Mouchbahani and associates (2004) proposed that the resistance should cause an increase in power output by increasing neural stimulation, but not cause a change in the pattern of muscle activity. Perhaps, strength ability determines the most appropriate load to use that will not alter running technique too dramatically. Is it possible that particular loads require a certain level of strength and power in order for the appropriate training stimulus to be achieved? Little or no information is available on the physical pre-requisites that may be required to perform resisted sled training appropriately. These physical pre-requisites need to be identified, together with the minimum muscular qualities (force/power) and/or loads an individual may need, in order to successfully perform resisted sled towing.

Reliability of Sprint & Jump Performance Measures

Reliability refers to the repeatability of an accurate measurement (Hunter, Marshall, & McNair, 2004b). Hopkins (2000) suggested a high level of reliability means a sports scientist can confidently detect small changes in an athlete's performance and use smaller sample sizes in research. Intraclass correlation coefficients (ICC) are used commonly and are based upon the results of an analysis of variance (ANOVA), which separates the error into variability between individuals and variability within an individual (error due to repeated measures) (Russek, 2004). Also commonly used is that of the coefficient of variation (CV) which is utilised to determine the similarity of measurement among trials (Cronin, McNair, & Marshall, 2003). This part of the review will focus on the reliability of some of the sprint and jump measures intended for use throughout the thesis.

Sprint Performance Measures

There are only a limited number of studies that have investigated the reliability of sprint performance measures. Coaching and sport science practice regularly employs sprints over 10 – 100 m as field tests of sprinting performance. It is, therefore, necessary to ascertain the most appropriate measurement tool for this assessment, whether a period of familiarisation is needed, and also which measures are reliable for specific genders, athletic populations, performance levels, and age groups.

The accuracy of the measuring device is important in order to ensure valid results. Photocell timing systems are used consistently to measure running performance. A photocell system consists of an emitter, reflector and detector. A beam from the emitter goes to the reflector located directly opposite, and is reflected back to the photocell sensor where it is detected (Yeadon, Kato, & Kerwin, 1999). In a study carried out by Yeadon, Kato, and Kerwin (1999) running speeds were calculated from photocell data using single beam and double beam systems,. An error of 0.1 $m.s^{-1}$ was achieved using a single beam system set at hip height with a longest break criterion for photocell separations of around two stride lengths.

Rimmer and Sleivert (2000) determined inter-trial and between-day ICC for the sprint time and kinematic variables used in their study. Inter-trial ICC values reported ranged from 0.94 - 0.98 for the 0 – 40 m times and from r = 0.80 - 0.89 for the 0 – 10 m times. Between-day ICC values ranged from r = 0.92 - 0.98 for the 0 – 10 m, 0 – 30 m, and 0 – 40 m times. The kinematic variables measured by Rimmer and Sleivert (2000) were average stride length, average stride frequency and ground contact (stance) time. The inter-trial ICC values for average stride length over the 10 and 40 m distances were r = 0.85 and 0.98, respectively, while the inter-trial ICC values for average stride frequency over 10 and 40 m were r = 0.62 and 0.82, respectively. Day-to-day ICC values for stride frequency and the number of strides taken ranged from r = 0.85 to 0.99. For the ground contact (stance) time variable, inter-trial ICC values were r = 0.76 and 0.85 for the contact times at the 7 m and 37 m marks, respectively. The day-to-day ICC value was r = 0.80 for contact time at the 7 m mark and r = 0.70 for contact time at the 37 m mark.

Often a familiarisation period is needed prior to a study testing session to ensure that a valid and reliable result is achieved by the participant, however this may not be the case for acceleration sprint performance according to the findings of Moir and colleagues (2004) . Ten physically active men attended five separate testing sessions over a three week period. No significant differences were discovered between the testing sessions for sprint performance. An ICC of 0.93 and 0.91 was determined for 10 m and 20 m sprint performance respectively. Coefficients of variation of 2.0% and 1.9% were also revealed for these sprints also. Moir and colleagues (2004) suggested that 10 m and 20 m sprint performance (as obtained from the best of three attempts) can achieve a high degree of reliability without the need to perform familiarisation sessions.

In a study conducted by Hunter, McNair and Marshall (2004b) the reliability of 26 kinematic and seven kinetic variables used in the biomechanical assessment of sprint running were determined. Video and ground reaction force data were collected at the 16 m mark from 28 male athletes as they performed maximal effort sprints. The most reliable variables were those that described the horizontal velocity of the body's G.G., whereas variables based on vertical displacement of the body's C.G. or braking ground reaction force were the least reliable. For all variables, reliability improved notably when the average score of multiple trials was the measurement of interest.

Jump Performance Measures

Vertical Jumps

Jump height is often used by coaches and physical conditioners to assess an athlete's power capability, due to its ease of administration and need for inexpensive and simple measuring devices. The most common vertical jumps employed in studies and the field seems to be the SJ and CMJ (Arteaga, Dorado, Chavarren, & Calbet, 2000; Kukolj et al., 1999; Markovic, Dizdar, Jukic, & Cardinale, 2004; Mero et al., 1983; Nesser et al., 1996; Ross, Langford, & Whelan, 2002; Young et al., 1995).

Arteaga and colleagues (2000) have reported coefficient of variation (CV) values of 5.4% and 6.3% for the SJ and CMJ height respectively of active males and females. Moir and colleagues (2004) reported CVs ranging from 1.9% to 2.6% for loaded and unloaded countermovement (CMJ) jumps and static (SJ) jumps, with ICCs ranging from 0.89 to 0.95. The authors suggested a high degree of reliability can be achieved without the need to perform familiarisation sessions, supporting the suitability of the tests for monitoring athletes and assessing the effects of experimental interventions and jump performance.

Literature pertaining to the reliability of force and power measures during vertical jumps is scarce. In a study conducted by Liebermann and Katz (2003) the mean peak relative power developed during a CMJ (measured on a force-measuring dynamometer based on strain gauge technology) was reported to remain significantly consistent after 1 – 4 days ($r = 0.92$) and also after five months ($r = 0.89$).

Horizontal Jumps

The horizontal assessments commonly used in research and predominantly by coaches and physical conditioners are the triple hop and single hop for distance (Bandy, Rusche, & Tekulve, 1994; Bolgla & Keskula, 1997; Paterno & Greenberger, 1996; Risberg, Holm, & Ekeland, 1995; Ross et al., 2002). Risberg and co-workers (1995) reported CV values of 2.0% and 2.4% for the distance jumped on the non-dominant and dominant legs respectively for the triple hop. High ICC have also been reported for the triple hop (ICC = 0.92 – 0.97) (Risberg et al., 1995; Ross et al., 2002) and single leg hop performed on the dominant leg (ICC = 0.92-0.96) (Bandy et al., 1994; Bolgla & Keskula, 1997; Paterno & Greenberger, 1996; Ross et al., 2002).

<u>Summary</u>

This literature review indicated that the sprint start from starting blocks and sprint running during the early acceleration phase are more complex than can be conceived. Although sprint performance may be affected by many factors, it is apparent that most recent world championship top three placed sprinters outperform their peers in the blocks and over the first 10 m of the race.

Factors to consider for an effective start appear to begin with the positioning of the starting blocks with a medium (30 – 50 cm) inter-block spacing and front block face angles set at a low angle (30 - 50°). In order to maximize the sprint start a quick reaction time in conjunction with an efficient start time (motor activity) is critical. The ability to develop large horizontal forces in a short time as to generate large horizontal impulses will result in high horizontal velocity when exiting the starting blocks. However, it is still unclear as to the most optimal start performance measure as different variables (e.g. start time, horizontal start velocity) have been used in the literature with no consensus being reached regarding the importance of these measures and which may best determine sprint running performance.

The founding strides of the early acceleration phase are important to the development of a high horizontal sprint velocity. The many phases of gait must be integrated as to optimize both step length and step frequency without the effect of negative interaction occurring. This can be achieved by the development of large horizontal impulses.

Bone lengths may be related to sprint performance, in particular step length, however more information is required in this area. Isoinertial strength and power assessments (e.g. squat jump and countermovement jump) appear to be better predictors of sprint performance than isokinetic strength and power measures. There appear to be more studies that have attempted to find relationships between sprint performance and vertical jumps as opposed to horizontal jumps, which is surprising as sprinting is predominantly horizontal in nature. Force measures relative to body mass are better predictors of sprint performance than the absolute measures, as this type of measure is more specific to sprint running which requires the ability to produce force relative to body mass against the ground in order to propel the body forward.

There is much experimental evidence pertaining to the improvement in initial acceleration utilising training methods such as weight training, plyometric training and various forms of resisted sprint training. However, one training method alone is not the best way to improve sprint performance. In fact it appears that combining sprint training with other forms of training (e.g. resistance, flexibility) better aids an improvement in sprint performance. It also appears that that there is much potential for research in the area of resisted sprint training. Interestingly there is no information in particular scientific justification on the possible changes resisted sled towing may have on sprint start performance from blocks or the best loads to utilise during training. Furthermore, no information is available on certain power pre-requisites an individual may need to perform resisted sled sprinting appropriately. Research is needed that examines these aspects of resisted sled sprinting from starting blocks. These types of studies will help in a better understanding as to which training methods will aid in the improvement of start and early acceleration sprint ability.

References for this chapter are included in the list of references on the last few pages of this thesis.

CHAPTER THREE

The Identification of the Best Sprint Start Performance Measure of Early Acceleration Sprint Performance and its Kinematic Determinants.

Prelude

It is still unclear as to what determines optimal sprint start performance even though it is critical to overall sprint running ability. There were two main purposes to this study: a) to investigate the sprint start (block) performance variable most related to 10 m sprint performance, and b) to determine the best kinematic predictors of both sprint start performance and 10 m sprint performance (i.e. sprint start and subsequent steps) separately. Ten male track sprinters performed short sprints from starting blocks. Video data was collected using two high speed cameras (250 Hz) during the blocks and up to the first three steps. Kinematic variables of the sprint start and first three steps were calculated. Statistical analyses included correlations and linear regression modelling. All statistical analyses were performed using SPSS Version 12.0. Mean horizontal block acceleration was discovered to be the most highly correlated kinematic variable to early acceleration performance ($r = 0.85$). Linear regression revealed that the ability to decrease the thigh angle at block takeoff with respect to the horizontal would result in a better sprint start. Sprint start ability as well as strong extensions of the front upper limb during step takeoff were found to be critical to early acceleration sprinting ability (10 m sprint time) as revealed through linear regression. The findings of this study further highlight the importance of sprint start ability to the final outcome of sprint performance. Coaches of track athlete's need to increase the mean horizontal block acceleration of their athletes in order to have an effective start, this can be achieved by increasing the horizontal component of the block forces as indicated by a more horizontal thigh angle at block takeoff.

Introduction

The 100 m event of a Track and Field competition is often among the most eagerly awaited and watched events of the meeting (Moravec et al., 1988). Success in this event involves the ability to cover the respective distance in the shortest possible time. For this reason, coaches, conditioners and sport scientists have long been examining how athletes can become faster.

A 100 m track sprint begins with the athlete in the crouch start position with their feet placed on the starting blocks according to rules of the International Amateur Athletic Federation (IAAF). Sprint start (block) performance and the subsequent early acceleration phases (10 m) have been suggested to be important to overall sprint performance in track and field (Coh et al., 1998; Harland & Steele, 1997). This is highlighted by the fact that many of the winners of the 100 m sprint event at a world champion level are the fastest to react in the staring blocks and also the fastest to a distance of 10 m (Ae et al., 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997).

Harland and Steele (1997) have reviewed the determinants of a good sprint start and have concluded that a successful start can be attributed to the ability to develop large horizontal forces at a high rate, not only in the blocks but also in the subsequent strides. Due to the complex nature of sprint starts it still appears unclear as to how these forces are best developed or what best defines sprint start performance as an independent measure. Often research investigating the determinants of sprint start performance will integrate the block start with the subsequent distance (Coh & Dolenec, 1996; Mero, 1988; Mero et al., 1983). However, as revealed by Coh and coworkers (1998) the block start has a very specific structure independent of the kinetic and kinematic parameters of the subsequent running phase (0 – 10 m). This therefore suggests the need for an independent sprint start performance measure.

Sprint start performance measures used in the literature include horizontal start velocity (Coh et al., 1998; Mero, 1988; Mero & Komi, 1986; Mero et al., 1983; Schot & Knutzen, 1992; Young et al., 1995), start time (Coh & Dolenec, 1996; Coh et al., 1998), and mean horizontal start acceleration (Delecluse et al., 1992). The relationship between these three start performance measures and sprint performance appears variable with correlation coefficients ranging from r = -0.03 to r = 0.71. Specifically, significant correlations between horizontal start velocity and sprint performance have been reported to range from r = -0.57 - -0.66 for male sprinters, where as for female sprinters insignificant correlations ranged from r = -0.43 - -0.58 over distances of 10 – 30 m (Coh et al., 1998). Coh and Dolenec (1996) reported correlations between start time and sprint performance between 10 – 30 m ranging from r = 0.41 - 0.70 . Mean horizontal start acceleration was reported to be correlated (r = 0.71) with sprint performance over 12 m (Delecluse et al., 1992). Some of these variations in reported correlations may be explained by the sprint distances used, subject characteristics or data analysis procedures used in these studies.

Perhaps there are better sprint start performance measures from those currently used in the literature. Examples could be maximum block velocity, mean horizontal block velocity, or a combination of start time and the mean horizontal block velocity (i.e. mean horizontal block acceleration). Identifying which performance measure is most related to overall sprint performance will allow a clearer understanding of the determinants of sprint start performance. This would have applications to sprint training and research.

There were two main purposes to this study: a) to investigate which sprint start (block) performance variables were most related to 10 m sprint performance, b) to determine the best kinematic predictors of both sprint start (block) performance and 10 m sprint performance (i.e. sprint start and subsequent steps) separately.

Method

Participants

Ten male (mean ± *SD:* age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 ± 0.36 s {10.37 – 11.42 s}) track sprinters of national or regional competitive level participated in the current study. Each subject gave written informed consent prior to participating in this study. Ethical approval was obtained for all testing procedures from The Human Subject Ethics Committee, Auckland University of Technology.

Procedure

Testing was conducted at an IAAF accredited athletic stadium with a Mondo track surface. Each athlete completed their own individual warm-up under the supervision of their coach. The athletes were invited to perform four 10 m sprints from a block start. The placement of the starting blocks was individually set according to the preference of the athlete. An experienced starter was used to provide standard starting commands to the athletes. The sprints were separated by a 2 - 3 minute rest period to ensure sufficient recovery. Athletes performed sprints in tight fitting clothing and spiked track shoes.

Data Collection

Figure 3.1 provides a schematic representation of the set-up procedures used during the testing session. Swift timing lights (80 Hz) were utilized to record the time from the start signal to the 10 m line. A microphone attached to a wooden start clapper was connected to the timing light handset. Timing was initiated when the appropriate sound threshold was broken. As sprint running from a block start involves body movements that occur predominately in the sagittal plane, a two-dimensional protocol was considered satisfactory for the present study. The set position, starting action (leaving the starting blocks) and initial acceleration (first few steps from the starting blocks) were filmed with two Fastcam PCI1000 cameras operating at 250 Hz with a shutter speed of 1/500 s. The cameras were placed perpendicular to the running direction, with overlapping fields, giving a sagittal view of the athlete for approximately three full running steps. The first camera registered the set position, starting action and one full step, whilst the second camera captured the movement of the athlete during the second and third steps. Both cameras were positioned 13 m from the athlete and elevated to 1.1 m (approximately hip height). Three marker strips were placed in the field of view so that one was visible in the overlapping view and towards the outer edge of each camera. These three markers ran across the lane with a strip placed parallel to the lane's long axis in the lane centre. These markers were used to calculate the measures of horizontal displacement. A 1.7 m tall rod fitted with a spirit level was filmed pre and post testing session at each of the three marker strips to enable the calculation of vertical displacement measures.

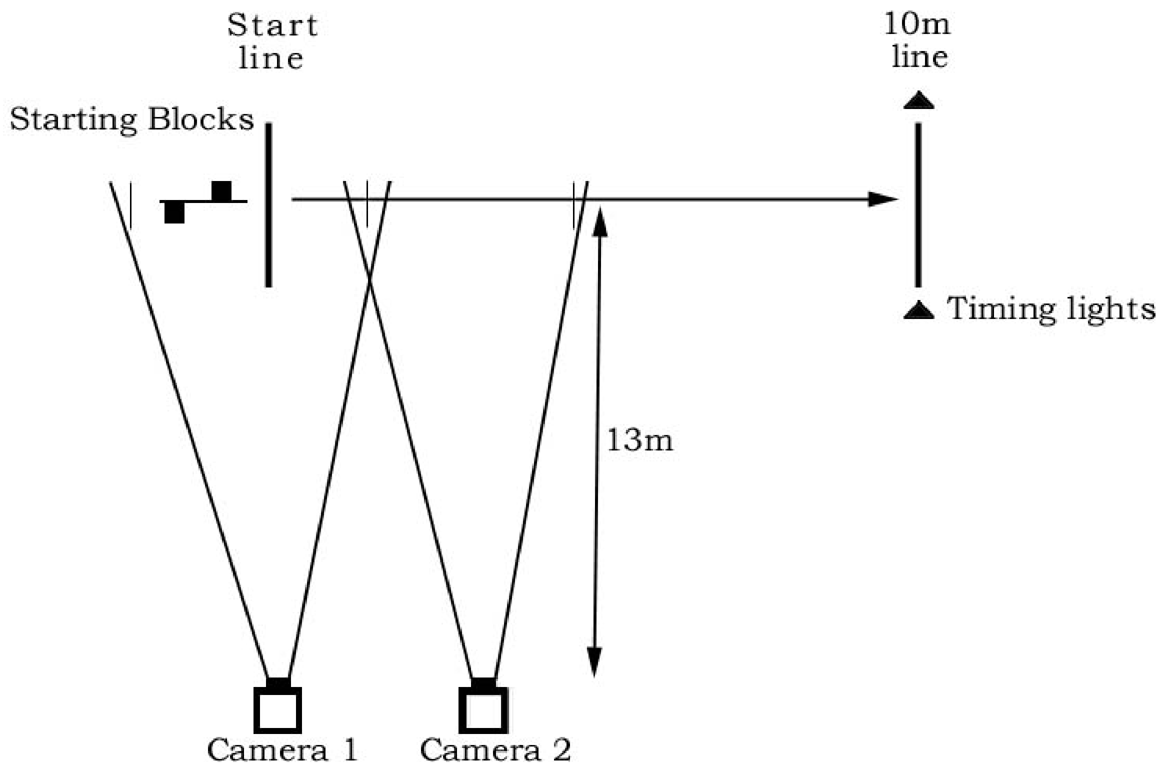


Figure 3.1. Equipment set-up used during data collection.

Data Analysis

High speed video footage collected from both cameras was analysed frame-by-frame to identify the x and y co-ordinates of the athlete's joints using a kinematic analysis system (Ariel Performance Analysis System, U.S.A.). Digitising began from the moment the starter's clapper closed till five frames post step three takeoff. Eighteen points of the body were digitized: apex of the head, 7th cervical vertebra, glenohumeral joints, elbows, wrists, third metacarpophalangeal joints, hips, knees, ankles, and distal ends of the feet (Johnson & Buckley, 2001). From these 18 points, human body segments were modeled. The segments included: trunk (shoulder to hip), head, upper arms, forearms, hands, thighs, shanks, and feet. The data was smoothed using a digital filter with a cutoff frequency of 8 Hz. The kinematic variables calculated for the block phase were:

Mean horizontal block velocity: the average horizontal velocity of the body's centre of gravity (C.G.) from the starters signal to the moment of leaving the blocks.

Maximum horizontal block velocity: the maximum horizontal velocity of the C.G. produced while in the blocks.

Horizontal start velocity: the horizontal velocity of the C.G. at the moment of leaving the blocks.

Mean horizontal block acceleration: the differential of mean horizontal block velocity.

Mean horizontal start acceleration: the differential of horizontal start velocity.

Reaction time: the time between the starters signal and the moment of first noticeable movement.

Hands off ground: the time between the starters signal and the last moment of hand contact with the ground.

Back leg off blocks: the time between the starters signal and the last moment of contact between the back leg and the blocks.

Start time: the time of the push-off action against the blocks from the moment of first noticeable reaction to last moment of contact with the blocks.

Total block time: (Also front leg off blocks) the time between the starters signal and the last moment of contact between the blocks and the front leg.

Time to maximum velocity as a percentage of total block time: the moment at which the maximum velocity produced in the starting blocks expressed as a percentage of total block time.

Flight time: the time from the moment of leaving the blocks to the first instant of ground contact of the first step.

Relative angles at takeoff from blocks: angles from the ankle, knee, hip, front shoulder, back shoulder, front elbow, and back elbow joints (see Figure 3.2).

Absolute angles at takeoff from blocks: angles from the shank, thigh, trunk, front upper arm, back upper arm, front forearm, and back forearm segments (see Figure 3.2).

Block push-off angle: the angle between the line passing through the front foot in the blocks and the hip of the same leg at the moment of leaving the blocks.

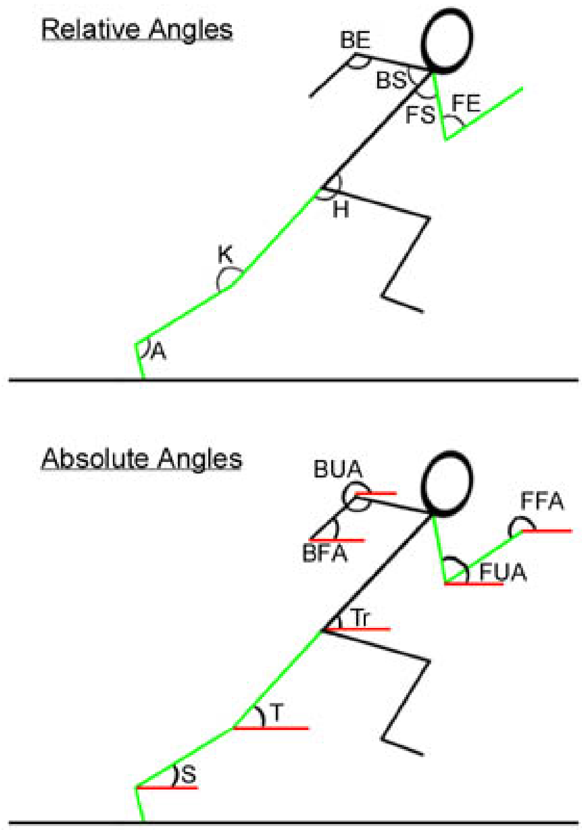


Figure 3.2. Relative and absolute angles measured during block takeoff, step touchdown and step takeoff.

Abbreviations: (BE = back elbow; BS = back shoulder; FS = front shoulder; FE = front elbow; H = hip; K = knee; A = ankle; BUA = back upper arm; BFA = back forearm; FUA = front upper arm; FFA = front forearm; Tr = trunk; T = thigh; S = shank).

All absolute angles were measured from the distal end (e.g. wrist for the lower arm segment) of the segment in a counterclockwise direction from the right hand horizontal plane.

Each step was split into a stance phase (ground contact) and flight phase (time in air). The stance phase was further divided into braking (negative horizontal reaction force) and propulsion (positive horizontal reaction force) sub-phases. Braking was determined from the instant of touchdown to the instant the horizontal velocity of the C.G. increased during stance (Mero et al., 1983). Propulsion was from the instant the horizontal velocity of the C.G. increased during stance to takeoff (Mero et al., 1983). Kinematic variables were determined for the first three steps from the starting blocks and then averaged to give an overall step average. The variables during the step calculated from the x and y coordinates were:

Step frequency: steps taken per second.

Step length: the horizontal distance between the point of touchdown of the foot to that of the following touchdown for the opposite foot.

Stance time: time of the stance phase.

Flight time: time of the flight phase.

Braking time: time of the braking phase.

Propulsion time: time of the propulsion phase.

C.G. stance distance: the horizontal distance the C.G. traveled during the stance phase (see Figure 3.3).

C.G. flight distance: the horizontal distance the C.G. traveled during the flight phase (see Figure 3.3).

C.G. braking distance: the horizontal distance the C.G. traveled during the braking phase.

C.G. propulsion distance: the horizontal distance the C.G. traveled during the propulsion phase.

Stance velocity at touchdown: the horizontal velocity of the C.G. at the instant of touchdown.

Mean stance velocity: the average horizontal velocity of the C.G. during the stance phase.

Flight velocity at takeoff: the horizontal velocity of the C.G. at the instant of takeoff.

Mean flight velocity: the average horizontal velocity of the C.G. during the flight phase.

Mean braking velocity: the average horizontal velocity of the C.G. during the braking phase.

B-P transition velocity: the horizontal velocity of the C.G. at the transition between the braking and propulsion phases.

Mean propulsion velocity: the average horizontal velocity of the C.G. produced during the propulsion phase.

Relative angles at touchdown and takeoff: angles from the ankle, knee, hip, front shoulder, back shoulder, front elbow, and back elbow joints (see Figure 3.2).

Absolute angles at touchdown and takeoff: angles from the shank, thigh, trunk, front upper arm, back upper arm, front forearm, and back forearm segments (see Figure 3.2).

Push-off angle: the angle between the line passing through the front foot in the blocks and the hip of the same leg at the moment of leaving the ground.

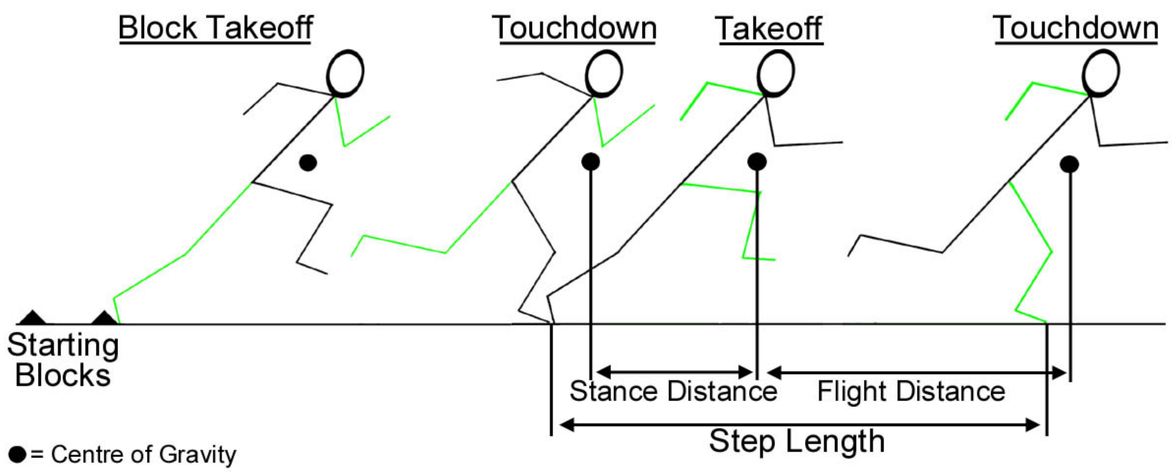


Figure 3.3. Sprint gait phases of interest (block takeoff, step touchdown and takeoff) and a representation of step length, stance distance and flight distance.

Statistical Analysis

Means and standard deviations were calculated for all kinematic variables from each subject's two fastest trials. Pearson's product-moment correlation coefficients were employed to establish relationships between sprint start (block) performance variables and 10 m sprint performance. A linear regression analysis was used to quantify the relationships between the dependent variables and selected kinematic independent variables. The predictive strengths of each variable were ranked according to the product of the regression coefficient – beta (β) and the standard deviation for repeated measurements of each variable. The slope of the regression line is known as the regression coefficient beta (β) (i.e. straight line equation is $y = \beta X + a$ where y = outcome measure, X = predictor measure, and a = the constant intercept). The regression coefficient beta indicates the amount of difference (increase or decrease) in the outcome measure (y) with a one-unit difference in the predictor measure (X) (Howell, 1992). The number of statistical tests that would be likely to return a significant result by chance alone (Type 1 error) can be calculated by calculating the alpha level by the total number of tests conducted (Hunter et al., 2004a). It is possible that one returned significant result would likely have occurred by chance alone due to 43 statistical tests being conducted (i.e. 0.01 x 43). Statistical significance was set at $p < 0.01$ for all analyses in all parts of the study in order to maintain an acceptable level of statistical power. All statistical procedures were performed using SPSS (version 12.0).

Results

<u>Part A: Identifying the best sprint start (block) performance predictor of 10 m sprint performance.</u>

Sprint performance times from a block start over 10 m ranged from 1.94 s to 2.14 s, with the group average being 2.04 ± 0.06 s. Disregarding the time spent in the starting blocks the average time to sprint 10 m was 1.61 ± 0.04 s (range 1.55 -1.70 s). Seven of the subjects reached maximal horizontal velocity prior to leaving the blocks. For these seven subjects, the time to reach maximal velocity was 93.5 ± 5.5% of total block time (range: 88.5% - 96.7%).

Correlations between sprint start performance variables and 10 m sprint time from a block start can be observed in Table 3.1. The start performance variable that was most significantly related to integrated early acceleration performance was the mean horizontal block acceleration (r = -0.85), with the variable expressing the lowest relationship being the maximum horizontal block velocity (r = -0.01).

Table 3.1. Means ± standard deviations of sprint start performance variables and their correlations with 10 m sprint time (s).

Sprint start performance variable	mean ± SD	r	r^2	p
Start time (s)	0.314 ± 0.028	0.77	0.59	0.009
Horizontal start velocity ($m.s^{-1}$)	3.40 ± 0.18	-0.06	0.01	0.862
Mean horizontal block velocity ($m.s^{-1}$)	1.50 ± 0.15	-0.79	0.63	0.006
Maximum horizontal block velocity ($m.s^{-1}$)	3.53 ± 0.19	-0.01	0.01	0.785
Mean horizontal start acceleration ($m.s^{-2}$)	10.93 ± 1.13	-0.70	0.49	0.024
Mean horizontal block acceleration ($m.s^{-2}$)	4.82 ± 0.86	-0.85	0.72	0.002

Part B: The kinematic determinants of sprint start (block) performance and 10 m sprint performance.

As mean horizontal block acceleration was more highly related to 10 m sprint performance than any other variable, the kinematic factors most related to mean horizontal block acceleration were investigated. The kinematic variables that were identified as significant predictors of sprint start (block) performance (mean horizontal block acceleration) are presented in Table 3.2. Mean horizontal block velocity was revealed to be most strongly related ($r = 0.93$, $p = 0.001$) to sprint start (block) performance. The linear regression coefficient identified that an increase in mean horizontal block velocity by 0.1 $m.s^{-1}$ (7%) would increase mean horizontal block acceleration by 0.55 $m.s^{-2}$ (11%). Linear regression models also predicted that a decrease in start time by 0.04 s (13%) would increase mean horizontal block acceleration by 1 $m.s^{-2}$ (21%). A decrease in the hands off ground time by 0.01 s (5%) would result in a 0.25 $m.s^{-2}$ (5%) increase in mean horizontal block acceleration. The time the athlete took to remove their hands from the ground during the start action was significantly correlated with start time ($r = 0.78$, $p = 0.008$), mean horizontal block velocity ($r = -0.82$, $p = 0.004$) and total block time ($r = 0.86$, $p = 0.001$).

A further 0.50$m.s^{-2}$ (10%) could be added to mean horizontal block acceleration if the thigh angle at block takeoff could be decreased by 3° (7%). Thigh angle was also significantly correlated with total block time ($r = 0.69$, $p = 0.026$), mean block velocity ($r = -0.73$, $p = 0.017$), and start time ($r = 0.78$, $p = 0.008$).

The best predictors of 10 m sprint performance from a block start (i.e. time to 10 m) can be observed in Table 3.3. Linear regression models revealed that a 0.50

$m.s^{-2}$ (10%) increase in mean horizontal block acceleration (sprint start performance) would decrease 10 m sprint time by 0.03 s (1.5%). It was also revealed that by increasing the shoulder angle of the front arm at step takeoff by 3° (10%), 10 m sprint time would be decreased by 0.01 s (0.5%). This 0.01 s decrease in 10 m sprint time would also occur if the front upper arm angle increased by 3° (4%) above the horizontal at step takeoff. These two front arm angles were significantly correlated with each other ($r = 0.98$, $p = 0.001$). The linear regression coefficient identified that a decrease in start time by 0.01 s (3%) would result in a faster 10 m sprint by approximately 0.02 s (1%). The athlete's average flight velocity of the C.G. during the step was also a predictor of 10 m sprint performance with a change of 0.1 $m.s^{-1}$ (2%) decreasing 10 m sprint time by 0.01 s (0.5%).

Table 3.2. Kinematic predictors of sprint start (block) performance (mean horizontal block acceleration (m.s^{-2})).

Rank	Predictor	Measure mean ± SD	Pearson correlations r	r^2	pvalue	Linear regression β	β x SD	SEE	%SEE
1	Mean horizontal block velocity (m.s^{-1})	1.50 ± 0.15	0.93	0.87	0.001	5.306	0.807	0.33	7
2	Start time (s)	0.314 ± 0.028	-0.90	0.81	0.001	-27.358	-0.766	0.40	8
3	Total block time (s)	0.430 ± 0.038	-0.88	0.77	0.001	-19.810	-0.753	0.44	9
4	Hands off ground time (s)	0.185 ± 0.031	-0.84	0.71	0.002	-23.487	-0.728	0.50	10
5	Block takeoff thigh angle (°)	43.0 ± 4.2	-0.79	0.63	0.006	-0.164	-0.684	0.56	12

Table 3.3. Kinematic predictors of 10 m sprint performance (10 m sprint time (s)).

Rank	Predictor	Measure mean ± SD	Pearson correlations r	r^2	pvalue	Linear regression β	β x SD	SEE	%SEE
1	Step takeoff front upper arm angle (°)	66.8 ± 17.4	-0.81	0.65	0.005	-0.003	-0.052	0.04	2
2	Mean horizontal block acceleration (m.s^{-2})	4.82 ± 0.86	-0.85	0.72	0.002	-0.058	-0.050	0.03	1
3	Block takeoff thigh angle (°)	43.0 ± 4.2	0.83	0.68	0.003	0.012	0.050	0.03	1
4	Step mean flight velocity (m.s^{-1})	5.12 ± 0.37	-0.84	0.70	0.003	-0.133	-0.049	0.03	1
5	Step takeoff front arm shoulder angle (°)	29.2 ± 12.2	-0.81	0.66	0.004	-0.004	-0.049	0.04	2
6	Mean horizontal block velocity (m.s^{-1})	1.50 ± 0.15	-0.79	0.63	0.006	-0.308	-0.047	0.04	2
7	Start time (s)	0.314 ± 0.028	0.77	0.59	0.009	1.594	0.045	0.04	2

Discussion

Part A: Identifying the best sprint start (block) performance predictor of 10 m sprint performance.

The mean horizontal block acceleration was discovered to be the sprint start performance variable with the strongest relationship to 10 m sprint time (r = -0.85), with 72% of the shared variance in 10 m sprint time being explained by this performance variable. This measure was a derivative of the horizontal block velocity (average velocity attained in the blocks) and start time, which were also both highly related to 10 m sprint performance (r = -0.79 & r = 0.77 respectively). Thus it is surprising mean horizontal block acceleration and horizontal block velocity have not been investigated in previous studies. Accordingly, sport scientists and track coaches could be interested in understanding the determinants of mean horizontal block acceleration.

Horizontal start velocity (the velocity of the C.G. at the moment of leaving the blocks) was not significantly correlated to 10 m sprint performance in the current study. This is surprising as horizontal start velocity has been used as a performance measure of sprint start ability by many researchers (Coh et al., 1998; Mero, 1988; Mero & Komi, 1986; Mero et al., 1983; Schot & Knutzen, 1992; Young et al., 1995). For example, Coh and coworkers (1998) reported strong relationships between horizontal start velocity and sprint performances over 10 m, 20 m, and 30 m and horizontal start velocity (r = -0.57, r = - 0.60, & r = -0.66 respectively) for male sprinters. The disparity between the results of the current study and the literature may partly be because most of the athletes in this study were not leaving the starting blocks at their highest velocity. However, the results of the present study indicated that even the maximum velocity attained during the block start phase was not highly related to 10 m sprint time.

Part B: The kinematic determinants of sprint start (block) performance and 10 m sprint performance.

Minimizing the time to 10 m from a block start is critical to 100 m sprint performance (Ae et al., 1992; Ferro et al., 2001; Moravec et al., 1988; Muller & Hommel, 1997). The results of the present study revealed that mean horizontal block acceleration (sprint start performance) was a very strong predictor of 10 m sprint performance. This further highlights the importance of a good start to sprint performance. Moderate increases in mean horizontal block acceleration were revealed to lead to small decreases in 10 m sprint time. These findings suggest that sprint coaches and their athletes may need to focus on ways in which to improve their ability to accelerate out of the starting blocks.

Strong relationships were also observed between sprint start (block) performance and that of mean horizontal block velocity and start time. This is not surprising as these are the key kinematic predictors of mean horizontal block acceleration. This suggests that there is an interaction between mean horizontal block velocity and start time with an optimal combination of these factors being required to maximize sprint start (block) performance. This is consistent with Schot and Knutzen (1992) who suggested that clearing the starting blocks in minimum time would not optimize sprint performance if subsequent movements were constrained in their efficiency. The amount of horizontal velocity produced is proportional to the magnitude of horizontal impulse (force x time) generated. The impulse will take into account the start time therefore it would be better to generate a high rate of force development (RFD). Coaches should encourage their athletes during training and competition to focus on generating a large horizontal impulse via an increased RFD over a short time in the starting blocks.

One way to achieve this increase in horizontal block impulse may be by changing the thigh angle at takeoff from the blocks. A more horizontal thigh angle at block takeoff was identified to be a good predictor of sprint start (block) performance. Findings of the present study revealed that by having the thigh in a more horizontal position at takeoff would result in small improvements sprint start (block) performance. This more horizontal thigh angle possibly results in a greater proportion of the ground reaction force being applied horizontally. With sprint start performance being predominantly horizontal in nature and requiring horizontal force application (Harland & Steele, 1997), it is not surprising that a more horizontal drive angle of the thigh at block takeoff was identified in the present study to be important to a successful start. Hoster and May (1979) stated that the drive angle during block take-off should be as low (horizontal) as possible. For that reason coaches should place some technical emphasis on teaching their sprint athletes to realise a more horizontal thigh angle at block takeoff as this may allow for a more horizontal force application which can increase sprint start (block) performance.

Upper limb joint kinematics (i.e. upper arm segment and shoulder joint angles of the front arm at step takeoff) over the first three steps were also significantly related to 10 m sprint time. These findings suggest that a more explosive arm drive and the subsequent greater front upper arm extension are important to 10 m sprint performance. This argument appears to be in agreement with previous recommendations. For example, Korchemny (1992) suggested that vigorous arm movements were one of the key elements to sprint performance. Hinrichs (1987) suggests that the arms provide the majority of the angular momentum needed to put the legs through their alternating strides in running. A greater extension of the upper arm can cause a greater contribution of momentum from the upper body to occur that possibly results in a longer stride action (Bhowmick & Bhattacharyya, 1988). In the present study large increases in shoulder angle and moderate increases in upper arm angle were discovered to lead to small improvements in 10 m sprint time. In light of these findings, coaches and athletes should focus training on emphasizing strong extensions of the front upper limb during step takeoff in order to improve early acceleration sprint performance.

Conclusion

In the present study mean horizontal block acceleration was discovered to be more highly related to 10 m sprint performance. Coaches and athletes should therefore focus their sprint start training on producing a large horizontal block velocity over a short period of time. The results of this study suggest that this may result from decreasing the thigh angle with respect to the horizontal at block takeoff. Sprinters should also emphasise strong front upper limb extensions during step takeoff in order to improve 10 m sprinting ability. The results obtained in this study are important for the optimisation of sprint start and 10 m sprint performance. At the same time they also enable a better guide to identify, control, and plan technical training strategies for track sprinters. Future research directions should include training this study's identified kinematic predictors examining whether or not they will lead to an improved sprint start or enhanced sprint running ability.

CHAPTER FOUR

Resisted Sled Training Methods for Early Acceleration Sprint Performance from Starting Blocks: Kinematic Alterations Due to Different Loading Schemes

Prelude

Resisted sled towing is a training modality used to increase force output of the active musculature during the early acceleration phase in sprint running. Augmented force output is critical to starting quickly and obtaining an early performance edge over other competitors. The purpose of this study was to examine the alterations in early acceleration sprint start kinematic variables as a result of resisted sled loading and, secondly, to identify the most appropriate loads to prescribe as a resistance when training. Ten male track sprinters completed a progression of sprints unresisted and with resistive loads of 10% and 20% body mass. High-speed video footage was collected at 250 Hz for the start and the first three steps of the sprinting action. Sagittal kinematic measures of the sprint start and first three steps were subsequently obtained using APAS motion analysis software. A repeated measures ANOVA using SPSS for Windows (version 12.0) determined if there was a significant ($p<0.01$) interaction between the kinematics under the various loaded conditions. Start kinematics that were significantly affected by load were total block time, start time, flight time from the blocks, block push-off angle, and block takeoff shank angle. Resisted sled loading did not change sprint start performance (mean horizontal block acceleration) but it did stimulate some key technical aspects such as start time and block push-off angle. Stimulating these two aspects of sprint start performance may lead to an enhanced sprint start, through a larger generation of force within the starting blocks and a more horizontal leaving position from the starting blocks. Additionally, step length may increase with resisted sled towing from more active ground contacts due to increased propulsive activity and increased flight phase capabilities. In all instances the load of 20% body mass was identified to be the most appropriate load to induce a sufficient change without a significant disruption to overall technique. Based upon these findings, coaches of track sprinters should consider resisted sled towing with a load of 20% body mass as a training tool for improving their athlete’s sprint start and early acceleration performance.

Introduction

Superior execution of the start and early acceleration phase is critical for achieving a performance edge over the competition in the short sprint events of Track and Field (Coh et al., 1998; Harland & Steele, 1997). Specifically, a successful sprint start requires the development of large horizontal forces at a high rate whilst in the blocks (Harland & Steele, 1997), resulting in a swift movement towards the founding strides (Mero, 1988; Mero et al., 1983). The primary goal of the founding strides is to generate a rapid sprint running velocity. Horizontal sprint velocity is the product of the length and rate (frequency) of the athlete's strides (Donati, 1996; Hay & Nohara, 1990; Hunter et al., 2004a). A stride is a complete running cycle from foot contact with the ground to the next ground contact with the same foot (Cavanagh & Kram, 1989), whereas a step is defined as the moment from foot contact of one foot to the contact of the opposite foot and is representative of a half cycle (Hunter et al., 2004a). Consequently two athletes with the same horizontal velocity may employ different stride strategies, such as a high step frequency and low step length, or vice versa (Hunter et al., 2004a). It has been reported, however, that stride strategies are related to the individual athlete's ability, with faster athletes having the capacity to employ a higher stride frequency (Murphy et al., 2003). Identifying training strategies that are appropriate for improving horizontal force production in the starting blocks, the length and frequency of the strides, and consequently overall sprint performance, may assist coaches and physical conditioners in the task of training sprinters.

Many coaches during the last 50 years have attempted to develop new training interventions to improve sprint performance by either increasing or decreasing performance parameters and conditions (Saraslanidis, 2000). One training method is resisted sled towing. Resisted sled towing is widely considered the most appropriate training technique to improve the strength of the muscles that are fundamental to sprint performance (Saraslanidis, 2000). The suggested benefits from using resisted sled towing are a faster start performance (Mouchbahani et al., 2004; Sheppard, 2004), an increased stride length (Delecluse, 1997), an increase in muscular force output of the lower body (Saraslanidis, 2000), and the development of specific recruitment patterns that target the fast-twitch muscle fibers (Lockie et al., 2003). Whilst resisted sled towing is a popular method for training acceleration performance in sprinters and field sport athletes, the effects of resisted sled towing has not yet been adequately quantified and is therefore not well understood.

Due to the paucity of resisted sled towing research it is still unclear as to which loads are the most appropriate to induce a significant training effect. The training stimulus induced by resisted sled towing is prescribed by securing weight plates to the sled's mass. The level of resistance imposed on the sprinter can be expressed as an absolute load (e.g. 5 kg) or relative to the individual's body mass (e.g. 5% body mass). The coaching and physical training literature advocates that absolute loading schemes (e.g. 5 kg) should be employed during resisted sled tow training (Letzelter et al., 1995; Mouchbahani et al., 2004; Saraslanidis, 2000). The limitation of prescribing absolute loads as a guideline for coaches, is that the athletes individual anthropometry (e.g. stature and mass), physical strength, and current sprint performance capabilities are not considered. The effect of resisted sled towing with a 10 kg load may, for example, enhance the performance of one athlete but be detrimental for another. Guidelines that recommend loads relative to body mass (e.g. 15% body mass) may be more appropriate, as these loads can be more adequately generalized across athletes irrespective of their stature or mass. Mouchbahani and associates (2004) suggested the use of a 5-10% body mass load when performing resisted towing. Whereas, Lockie, Murphy, and Spinks (2003) suggested that a 12.6% body mass load was required to enhance hip flexion during the leg drive phase, resulting in improvements to the length and rate of the strides but with minimal disruption to technique. However, the authors contended that a load of 32.2% body mass was better for developing the upper body action during accelerative sprinting. Although these guidelines offer some insight into loading schemes to employ for certain technical aspects of sprint running, it is still unclear as to the appropriate magnitude of the loads to utilise. It may be that loads other than those suggested by Lockie, Murphy, and Spinks (2003), and Mouchbahani and associates (2004) are more appropriate at stimulating technical aspects of sprint running.

A further issue to consider when prescribing resisted sled loading is whether the individual's sprint technique is being positively or negatively altered as the athlete is sprinting with the added resistance. The amount of technique disruption that is acceptable when training a sprinter with an added load has not been widely debated. Jakalski (1998), for example, suggests that athletes should not be slowed down more than 10%, due to the changes in ground contact dynamics. Further, Mouchbahani and associates (2004) proposed that the resistance should cause an increase in power output by increasing neural stimulation, but not cause a change in the pattern of muscle activity.

Past research has revealed that resisted sled towing causes acute alterations in sprint kinematics of the early acceleration phase (Letzelter et al., 1995; Lockie et al., 2003). Kinematics such as stride frequency and stride length have been reported to decrease, where as stance time, trunk and hip angles have been reported to increase as a consequence of this training method (Letzelter et al., 1995; Lockie et al., 2003; Mouchbahani et al., 2004). Though these kinematic alterations seem somewhat arbitrary in the short term, it is possible that they may lead to future improvements in acceleration sprint performance. Although resisted sled towing has been promoted as a useful tool for improving sprint start performance (Mouchbahani et al., 2004; Sheppard, 2004), no studies have examined the effects of this training modality on sprint start kinematics. The identification of the kinematic alterations to sprint start technique that result from resisted sled loading, if any, would provide informative information on whether or not this training tool is beneficial for attempting to improve sprint start performance.

The purpose of this study was, therefore, to examine the changes to block start and early acceleration sprint kinematics with resisted sled loading and, secondly, to identify the most appropriate loads to prescribe as a resistance when training.

Method

Participants

Ten male (mean ± *SD:* age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 ± 0.36 s {10.37 – 11.42 s}) track sprinters at a national and regional competitive level participated in the current study. Each participant gave written informed consent to participate in this study prior to testing. Ethics approval was obtained for all testing procedures from the university ethics committee.

Procedure

Testing was conducted at an IAAF accredited athletic stadium with a Mondo track surface. Each athlete completed their own individual warm-up under the supervision of their coach. The athletes were then asked to perform twelve 10 m sprints from a block start under three experimental conditions. The conditions used were unresisted sprinting and resisted sprinting with two different loads (10% body mass and 20% body mass). The loads tested were selected based upon what was frequently used by the coaches of these athletes. A metal sled weighing 7 kg was employed in this study (see Figure 4.1). A nylon rope 30 m in length was used to connect the athlete to the sled via a waist harness. The rope length of 30 m was selected as it produced a relatively horizontal (within 1 - 2°) angle of pull when considering the height of the athlete's hips in the starting blocks and performing a basic trigonometric sine function (see Figure 4.2). The 30 m rope length also allowed a sufficient deceleration distance after the 10 m sprint, so that the sled wouldn't crash into the starting blocks. All experimental conditions were allocated randomly to each participant in order to minimize testing bias. The placement of the starting blocks was individually set according to the preference of the individual athlete. An experienced starter was used to provide standard starting commands to the athletes. The sprints were separated by a 2 - 3 minute rest period to ensure sufficient recovery. Athletes performed sprints in tight fitting clothing and track spike shoes. The two fastest unresisted and resisted (10% and 20% body mass) trials were averaged and used in the data analysis.

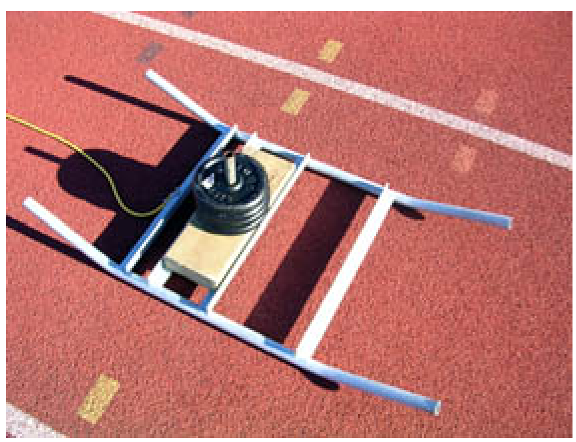


Figure 4.1. Metal sled used for resisted sled towing.

Figure 4.2. The attachment of the sled to the athlete in the starting blocks.

Data Collection

Figure 4.3 provides a schematic representation of the set-up procedures used during the testing session. Swift timing lights (80Hz) were utilized to record the time from the start signal to the 10 m line. A microphone attached to a wooden start clapper was connected to the timing light handset. Timing was initiated when the appropriate sound threshold was broken. As sprint running from a block start involves body movements that occur predominately in the sagittal plane, a two-dimensional protocol was considered satisfactory for the present study. The set position, starting action (leaving the starting blocks) and initial acceleration (first few steps from the starting blocks) were filmed with two Fastcam PCI1000 cameras operating at 250 Hz with a shutter speed of 1/500 s. The cameras were placed perpendicular to the running direction, with overlapping fields, giving a sagittal view of the athlete for approximately three full running steps. The first camera registered the set position, starting action and one full step, whilst the second camera captured the movement of the athlete during the remaining two steps. Both cameras were positioned 13 m from the athlete and elevated to the athlete's approximate hip height of 1. 1 m. Three marker strips were placed in the field of view so that one was visible in the overlapping view and towards the outer edge of each camera. These three markers ran across the lane with a strip placed parallel to the lane's long axis in the lane centre. These markers were used to calculate the measures of horizontal displacement. A 1.7 m tall rod fitted with a spirit level was filmed pre and post testing session at each of the three marker strips to enable the calculation of vertical displacement measures.

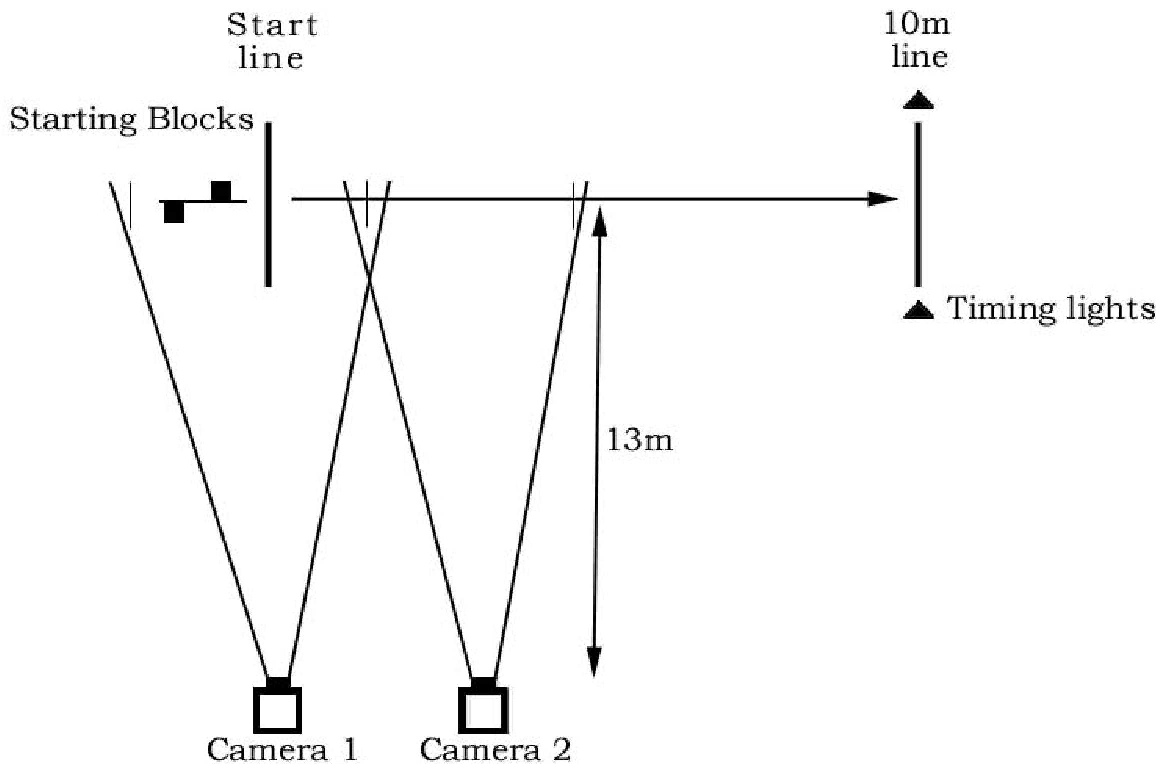


Figure 4.3. Equipment set-up used during data collection.

Data Analysis

High speed video footage collected from both cameras was analysed frame-by-frame to identify the x and y co-ordinates of the athlete's joints using a kinematic analysis system (Ariel Performance Analysis System, U.S.A.). Digitising began from the moment the starter's clapper closed till five frames post step three takeoff. Eighteen points of the body were digitized: apex of the head, 7^{th} cervical vertebra, glenohumeral joints, elbows, wrists, third metacarpophalangeal joints, hips, knees, ankles, and distal ends of the feet (Johnson & Buckley, 2001). From these 18 points, human body segments were modeled. The segments included: trunk (shoulder to hip), head, upper arms, forearms, hands, thighs, shanks, and feet. The data was smoothed using a digital filter with a cutoff frequency of 8 Hz for all x and y co-ordinates. The variables during the block phase calculated from the x and y coordinates were:

Mean horizontal block acceleration: the combination of mean horizontal block velocity and start time.

Reaction time: the time between the starters signal and the moment of first noticeable movement.

Hands off ground: the time between the starters signal and the last moment of hand contact with the ground.

Back leg off blocks: the time between the starters signal and the last moment of contact with the blocks of the back leg.

Start time: the time of the push-off action against the blocks from the moment of first noticeable reaction to last moment in contact with the blocks.

Total Block time: (Also front leg off blocks) the time between the starters signal and the last moment of contact with the blocks of the front leg.

Flight time: the time from the moment of leaving the blocks to the first instant of ground contact of the first step.

Mean horizontal block velocity: the average horizontal velocity of the body's centre of gravity (C.G) produced between the starters signal and the moment of leaving the blocks.

Relative angles at takeoff from blocks: angles from the ankle, knee, hip, front shoulder, back shoulder, front elbow, and back elbow joints (see Figure 4.4).

Block push-off angle: the angle between the line passing through the front foot in the blocks and the hip of the same leg at the moment of leaving the blocks.

Absolute angles at takeoff from blocks: angles from the shank, thigh, trunk, front upper arm, back upper arm, front forearm, and back forearm segments (see Figure 4.4).

All absolute angles were measured from the distal end (e.g. wrist for the lower arm segment) of a segment going in a counterclockwise direction from the horizontal plane.

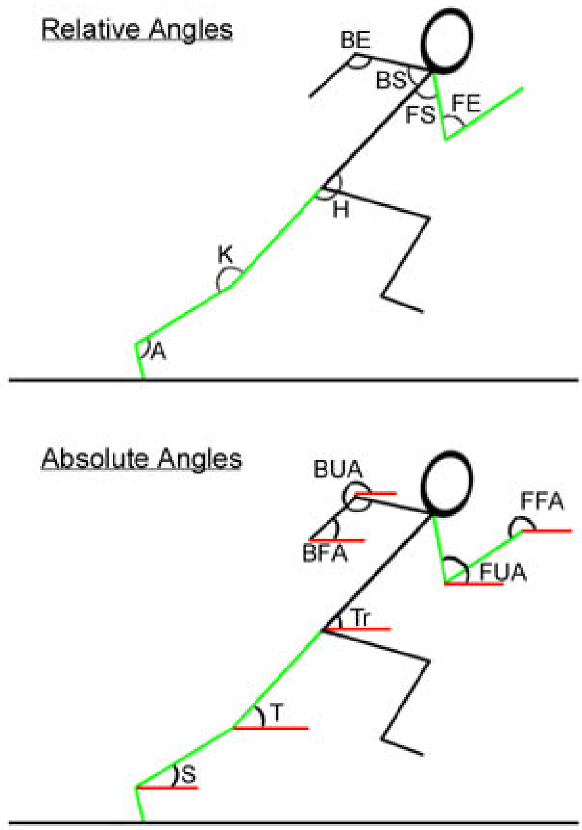


Figure 4.4. Relative and absolute angles measured during block takeoff, step touchdown and step takeoff .

Abbreviations: (BE = back elbow; BS = back shoulder; FS = front shoulder; FE = front elbow; H = hip; K = knee; A = ankle; BUA = back upper arm; BFA = back forearm; FUA = front upper arm; FFA = front forearm; Tr = trunk; T = thigh; S = shank).

Each step was split into two major phases consisting of a stance phase (ground contact) and flight phase (time in air). The stance phase was further described and analyzed as braking (negative horizontal reaction force) and propulsion (positive horizontal reaction force) sub-phases. Braking was determined from the instant of touchdown to the instant the horizontal velocity of the C.G increased during stance (Mero et al., 1983). Kinematic variables were determined for the first three steps from the starting blocks and then averaged to give an overall step average. The variables during the step calculated from the x and y coordinates were:

Step frequency: steps taken per second.

Step length: the horizontal distance between the point of touchdown of the foot to that of the following touchdown for the opposite foot (see Figure 4.5).

Stance time: time of the stance phase.

Flight time: time of the flight phase.

Braking time: time of the braking phase.

Propulsion time: time of the propulsion phase.

C.G stance distance: the horizontal distance the C.G traveled during the stance phase (see Figure 4.5).

C.G flight distance: the horizontal distance the C.G traveled during the flight phase (see Figure 4.5).

C.G braking distance: the horizontal distance the C.G traveled during the braking phase.

C.G propulsion distance: the horizontal distance the C.G traveled during the propulsion phase.

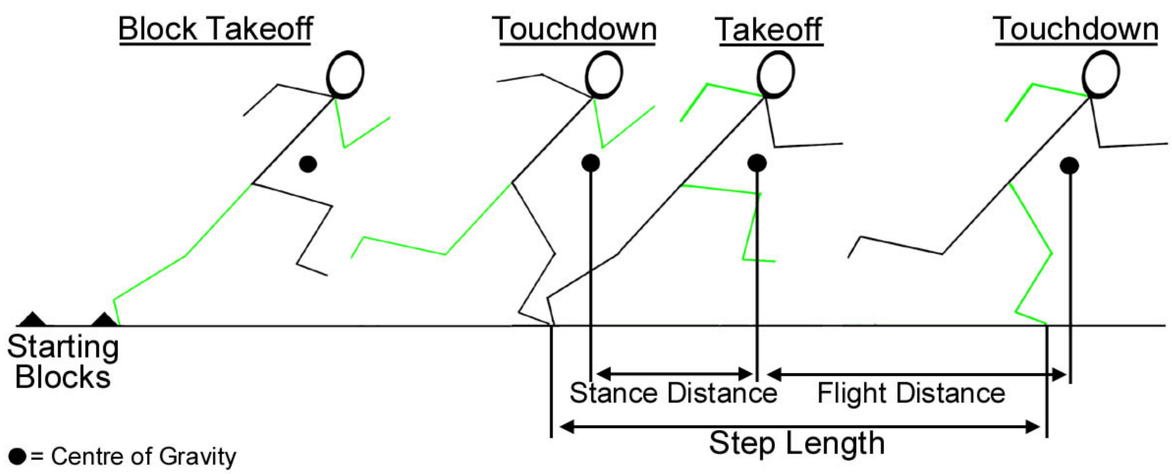


Figure 4.5. Sprint gait phases of interest (block takeoff, step touchdown and takeoff) and a representation of step length, stance distance and flight distance.

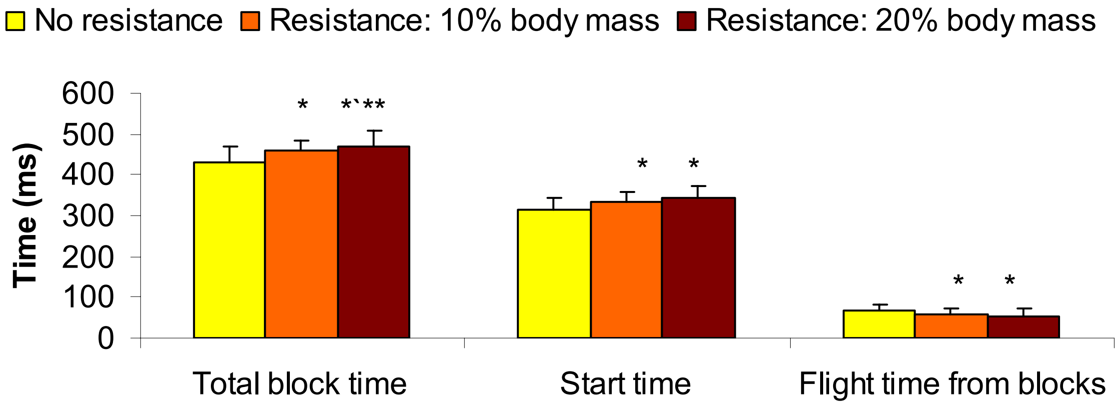
Statistical Analysis

Means and standard deviations were calculated for each of the dependent and independent measures of the two fastest trials. A repeated measures ANOVA was used to determine if there was a significant interaction between the kinematics under the various loaded conditions. Statistical significance was set at $p < 0.01$ for all analyses. The number of statistical tests that would be likely to return a significant result by chance alone (Type 1 error) can be calculated by multiplying the alpha level by the total number of tests conducted (Hunter et al., 2004a). It is possible that 0.33 of the 11 returned significant results would likely have occurred by chance alone due to 33 statistical tests being conducted (i.e. 0.01 x 33). All statistical procedures were performed using SPSS for Windows 12.0.

Results

Sprint times for the unresisted 10 m sprint from a block start ranged from 1.94 s to 2.14 s ($\overline{X}$ = 2.04 ± 0.06 s). The sprint times became slower when the athletes were connected to the sled towing device (main effect: *p* = 0.001; 0% vs. 10%; *p* = 0.001; 0% vs. 20%: *p* = 0.001). Sprinting performance with a load of 10% body mass ranged from 2.15 s to 2.26 s ($\overline{X}$ = 2.20 ± 0.04 s), and from 2.24 s to 2.38 s ($\overline{X}$ = 2.32 ± 0.05 s) with a 20% body mass. Thus a resistance load of 10% and 20% body mass reduced 10 m sprint time by approximately 8% (0.16 s) and 14% (0.28 s) respectively. Mean sprint time with a 20% body mass load was approximately 6% slower (0.12 s) than mean sprint time with a load of 10% body mass (*p* = 0.001).

Kinematic alterations of the sprint start phase were the primary interest of this study. A small number of sprint start kinematics were significantly ($p<0.01$) affected by a resisted sled load of 10% and 20% body mass. The temporal sprint start kinematic variables of total block time, start time, back leg off block time, and flight time from the blocks are presented in Figure 4.6. Generally the introduction of the resisted sled towing tool decreased the key temporal measures by 5-20%. Total block time (unresisted $\overline{X}$ = 430 ± 38 ms), for example, was 29 ms (7%) slower with a 10% body mass resistance ($\overline{X}$ = 459 ± 25 ms, *p* = 0.001), and 40 ms (10%) slower with a 20% body mass load ($\overline{X}$ = 470 ± 36 ms, *p* = 0.004). Whereas, flight time from the blocks with no resistance ($\overline{X}$ = 67 ± 14 ms) was approximately 16% (11 ms) and 21% (13 ms) longer than with a 10% body mass load ($\overline{X}$ = 56 ± 16 ms, *p* = 0.002) and 20% body mass load ($\overline{X}$ = 54 ± 20 ms, *p* = 0.012) respectively. The 10% body mass load conditions start time ($\overline{X}$ = 332 ± 24 ms, *p* = 0.004) was approximately 6% (18 ms) longer than the condition with no resistance ($\overline{X}$ = 314 ± 28 ms). Start time with a 20% body mass load ($\overline{X}$ = 344 ± 29 ms, *p* = 0.006) was also longer by approximately 10% (30 ms) compared with sprinting with no resistance.



Key: * = Significantly (p<0.01) different from no resistance
** = Significant (p<0.01) differences between 10% body mass and 20% body mass loads

Figure 4.6. Changes in temporal sprint start kinematics as a result of resisted sled loading (Mean (±1SD)).

Under added resistance a more horizontal push-off angle (main effect: p = 0.005; 0 % vs. 10%; p = 0.007; 0 % vs. 20 %: p = 0.001) and shank angle (main effect: p = 0.002; 0 % vs. 10%; p = 0.001; 0 % vs. 20 %: p = 0.001) at takeoff from the starting blocks occurred. Figure 4.7 highlights these spatial variables (e.g. relative and absolute angles) during block takeoff that were altered as a result of resistance loading. Compared with the 10% load no greater change to these spatial kinematics was observed with the 20% load.

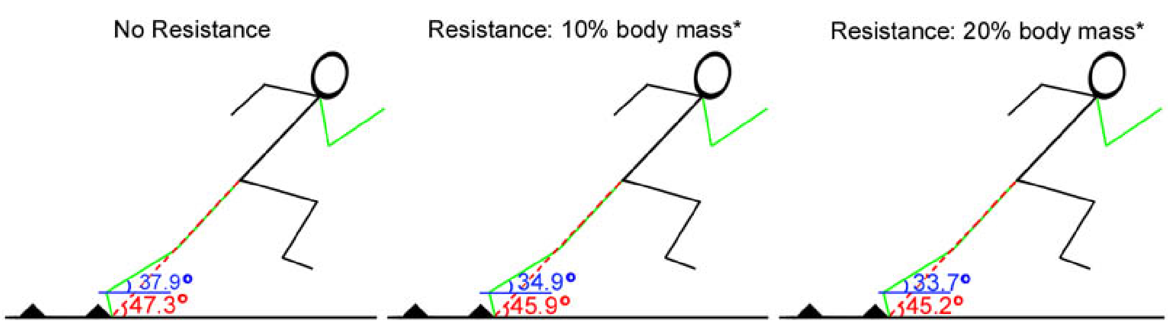


Figure 4.7. Decreases in block push-off angle (red font) and block takeoff shank angle (blue font) over the three test conditions. * Significantly (p<0.01) different from condition with no resistance.

Table 4.1. Step length, stance time, propulsion time, flight time, and flight distance over the three test conditions.

	No Resistance (Mean±SD)	Resistance: 10% (Mean±SD)	Resistance: 20% (Mean±SD)
Step length (m)	1.25 ± 0.10	1.16 ± 0.10*	1.13 ± 0.11*
Stance time (ms)	180 ± 21	188 ± 18*	201 ± 25*
Propulsion time (ms)	152 ± 19	161 ± 14*	165 ± 20*
Flight time (ms)	55 ± 10	54 ± 8*	46 ± 8*,**
Flight Distance (m)	0.31 ± 0.08	0.27 ± 0.03*	0.21 ± 0.03*,**

BM = Body mass

* Significantly (p<0.01) different from no resistance

** Significant (p<0.01) differences between 10% body mass and 20% body mass load

The initial accelerative steps of the athlete once they had left the starting blocks were of further interest in this study. Resisted sled loading led to shorter steps (p<0.01). Decreases in step length (main effect: p = 0.001; 0 % vs. 10%; p = 0.001; 0 % vs. 20 %: p = 0.001) can be observed in Table 4.1. None of the loads altered this kinematic significantly more than the other, in fact both loads induced similar alterations to step length of approximately 7-10% (0.090 – 0.12 m).

Kinematics of the step sub phases (stance and flight) that were altered due to resisted sled towing are presented in Table 4.1. Generally resisted sled towing resulted in greater active ground contacts and reduced flight phase capabilities. This was evident from significant increases in stance (main effect: p = 0.010; 0 % vs. 10%; p = 0.010; 0 % vs. 20 %: p = 0.010) and propulsion times (main effect: p = 0.003; 0 % vs. 10%; p = 0.032; 0 % vs. 20 %: p = 0.007). A load of 10% body mass increased stance time and propulsion time by approximately 5% (8 ms) and 7% (9 ms) respectively. The 20% body mass load led to an increase of approximately 12% (21 ms) for stance time and 10% (13 ms) for propulsion time. A load of 20% body mass only was revealed to significantly change step flight time (p = 0.01) by 9 ms (15%) and step flight distance (p = 0.01) by 0.1 m (25%) from unresisted sprinting.

Discussion

Resisted sled towing is a sprint specific training method employed by many coaches in an attempt to improve the sprint acceleration ability of their athletes. Furthermore, resisted sled towing has been promoted as a useful tool for improving sprint start performance (Mouchbahani et al., 2004; Sheppard, 2004). However, the block start and early acceleration in the short sprint events is highly technical (Harland & Steele, 1997), and no studies have examined the effects resisted sled towing has on sprint start kinematics. Sprint start performance (mean horizontal block acceleration) was unaffected by added resistance. Further, many of the kinematics during the sprint start were unaltered as a result of resisted sled towing. Resisted loading did not effect, for example, mean horizontal block velocity, reaction time, and the total time taken to remove both hands off the ground. However, kinematic measures such as start time and block push-off angle identified to change when the athlete was attached to the sled device, may benefit from resisted sled tow training and lead to an enhancement in sprint start performance.

The aim of the block start is to activate the correct sequence of muscular activity so that maximal force production occurs (Harland & Steele, 1997), whilst leaving the blocks in the shortest possible time (Helmick, 2003). Resisted sled towing led to increased start time, which possibly suggests that greater motor activity is occurring within the hip and lower limb musculature. Intuitively, a greater load would require the production of a greater force to overcome the inertia of the object. This greater force requirement will result in a greater recruitment of additional motor units available within the muscle, or possibly increase the rate of neural impulses to the already recruited motor units (Deschenes, 1989). These neural activation qualities are considered important for a superior sprint performance (Ross, Leveritt, & Riek, 2001). The results of the current study suggest that resisted sled towing may be a useful tactic to increase force production and the muscle activity during the time from reacting to the start signal to leaving the starting blocks (start time), which in turn may improve start performance. The increase in start time was less than 10% for both loads, indicating that either load would be appropriate to use for improving start time. Therefore, if a successful block start requires the production of large horizontal forces in the blocks (Harland & Steele, 1997), resisted sled towing with a load of 20% body mass would be an excellent training tool to use to improve sprint start performance as the greater mass would result in a greater force production.

When coaching the sprint start, technical emphasis is placed on leaving the starting blocks in a more horizontal position. Resisted sled towing with either a 10 or 20 % load revealed that athletes adopted a more horizontal push-off or drive angle out of the starting blocks. This was more than likely due to the greater inertia restricting the ability of the athlete to move vertically. Hoster and May (1979) stated that the drive angle during block take-off should be as low (horizontal) as possible. If the angle of takeoff is shifted closer to the horizontal it is likely that an increase in step length would occur providing the takeoff velocity remains the same. Increases in the length of the first steps out of the starting blocks has been advocated as part of an optimal start (Korchemny, 1992). The findings of the current study indicated that either training load would be appropriate to use during resisted sled tow training in order to increase the horizontal drive out of the blocks, however, the heavier load did put the athlete in a slightly more horizontal position. Hence, resisted sled towing with a load of 20% body mass may be useful for athletes who propel themselves in a more vertical direction as opposed to a horizontal direction out of the starting blocks.

Once the athlete has left the starting blocks the athlete attempts to increase their step length and step frequency in order to maximize their horizontal sprint velocity therefore resulting in a quicker sprint time. Hence, a great deal of coaching emphasis is placed on improving step length and/or step frequency under the contention that improving one of these factors will lead to faster sprint running performance. The literature suggests that resisted sled towing will lead to an increased stride length and possibly higher step frequency (Artingstall, 1990; Delecluse, 1997). In the current study resisted sled loading led to shorter steps being performed at a similar turnover rate to that employed during unresisted sprinting. Past research has reported similar adaptations to step length with the attachment of added resistance (Letzelter et al., 1995; Lockie et al., 2003). It seems detrimental to sprint performance that resisted sled towing leads to a diminished step length. However, there may be some potential benefits likely to occur during the stance and flight phases which may lead to a future improvement in step length when sprinting with no resistance.

Stance and propulsion times increased significantly with added resistance, which is consistent with past resisted sled towing literature (Letzelter et al., 1995; Lockie et al., 2003). The increase in stance time in the current study would have been due to the increase in propulsion time. This finding suggests that a more active foot contact occurs which may be due the requirement for a greater propulsive force to overcome the inertia of the greater load. This results in a longer propulsion/stance time to produce sufficient force to propel the individual into the next step. Hunter, Marshall, and McNair (2004a) have suggested directing most training effort at producing large ground reaction impulses (force x time) particularly in the horizontal direction as this will increase both step length and step rate. It may be that increased stance and propulsion times during sprinting with a resisted sled will lead to an increased step length during unresisted sprinting in the long term due to enhanced capabilities of producing larger forces during ground contact. Both resisted sled loads induced a similar change in the current study with changes in technique decreasing by approximately 10%. However, due to the potential benefits of greater force production due to greater force requirement to move the heavier resistance it is suggested that resisted sled training be performed with a 20% body mass load.

Resisted sled loading caused step flight time and step flight distance to decrease. It is still unclear whether flight time during the early acceleration phase influences sprinting performance and if such a relationship would be negative or positive in nature. Intuitively the more time spent in the air would mean less time spent in contact with the ground or a less frequent occurrence of ground contact. Hunter and colleagues (2004a) suggested more frequent ground contacts (stance phases) through the means of a low vertical ground reaction impulse (force x time) and short flight time would allow a greater opportunity for the athlete to accelerate. Alternatively greater flight kinematic variables may be advantageous during the early stages of acceleration sprinting. It was made evident in the current study that one of the loads would be better than the other to employ to induce a change in step flight time and step flight distance. This was discovered through significant differences existing between the two loads, but not between one of the loads and sprinting with no resistance. In all these instances a load of 20% body mass was the only load that was identified to significantly alter step flight time and step flight distance. This finding is in accordance with those reported by Lockie, Murphy, and Spinks (2003) for the variable of step flight time. Therefore the findings of the current study suggest that resisted sled towing with a 20% body mass load could possibly be useful to improve both step flight time and step flight distance. An improvement in these two step flight kinematics could lead to an improvement in step length (Hunter et al., 2004a), which supports the contention that resisted sled towing may lead to an improvement in step length (Delecluse, 1997).

Conclusion

If the training goal of the track and field sprints coach or athlete is to improve sprint start performance the results of this study suggest resisted sled towing to be an excellent training tool to employ in an individuals training regime to aid this training goal. This was due to increased force output within the starting blocks without a significantly detrimental affect on sprint start kinematics. Although sprint start performance was not directly altered as a result of resisted sled towing, two vital sprint start kinematics, start time and block push-off angle, may benefit from the added resistance which would lead to an enhancement in sprint start performance. It is recommended that a resisted sled load of 20% body mass be employed to induce an adaptation for the key sprint start technical coaching aspects start time and block push-off angle. Specifically, a load of 20% body mass, will allow for a large generation of force within the starting blocks, and cause a more horizontal leaving position from the starting blocks, whilst causing minimal disruption to technique. Potentially a load of 20% body mass may be also advantageous for improving the athlete's ability to increase their step length through a greater propulsive ability and increased flight phase capabilities which may improve sprint running in the long term. However, the current study examined the effects of loads of 10 and 20 % on sprint start and acceleration performance. A load of 15% body mass could be a more effective training load, however further research is required to answer this question. Additionally future research is required investigating the long term adaptations that resisted sled towing may have on both sprint performance and sprint kinematics of the start and early acceleration phases.

References for this chapter are included in the list of references on the last few pages of this thesis.

CHAPTER FIVE

Physical and Training Pre-requisites for Start and Sprint Acceleration Performance With and Without Sled Resistance

Prelude

The track and field sprint start and early acceleration phases are considered important aspects in the final outcome of the short sprint events (100 m, 200 m). Despite deficient empirical evidence, training techniques such as plyometrics and resisted sled towing are commonly utilised with the belief that they enhance acceleration performance. The purpose of this study was to identify the physical pre-requisites for resisted and unresisted sprint acceleration performance from a block start. Ten male sprinters performed twelve 10 m sprints from a block start under unresisted and resisted (10% & 20% body mass) sled conditions. Each athlete also completed an anthropometric assessment (height, mass, 3 bone lengths, 2 bone widths) and a variety of vertical and horizontal jump tests (3 trials each). Linear regression analysis determined whether there was a significant relationship ($p \leq 0.05$) between any of the predictor measures and the outcome variables of 100 m personal best time, or 10 m sprint performance with or without resistance (10 & 20% body mass). Pearson correlations revealed that sprinting with 10% resistance may be insufficient for a significant improvement in 10 m sprint performance. A key quality that indicated the athletes unresisted 10 m sprint performance was the relative explosive ability of the sprinters hip and knee extensors during the countermovement jump. The straight leg jump test was revealed to be a good predictor of resisted sprint starts due to its increased emphasis on lower leg explosiveness. Coaches of track athlete's should consider the countermovement jump as a training exercise to improve both 10 m and 100 m sprint performance. For the coach intending on employing resisted sled towing in their athlete's training regime a load of 20% body mass would be the most appropriate, especially for athletes with a 10 m sprint time from blocks below 2.10 s.

Introduction

High performance sprint running from a block start requires the production of both high level forces and angular velocities (Harland & Steele, 1997; Mero et al., 1992; Mero et al., 1983). On and off-track resistance training, therefore, underpins the athletic program of the competitive sprinter (Delecluse et al., 1995). In the gymnasium the weighted squat jump, for example, is employed to increase the power of the hip and lower limb musculature. On the track, resisted sled towing is utilised to load the athlete to increase the hip drive and ground contact propulsion of the sprinting strides. Interestingly, studies pertaining to the changes in sprint start performance from blocks induced by any training strategy are scarce to nonexistent. This is perplexing as many methods are employed in the field without any empirical evidence that demonstrates a favourable ability to improve this phase of sprint running. The effects of, for example, jump training, strength training, resisted sled towing or standard block start training methods on the start and early acceleration phases are not well understood. Seemingly fundamental to the employment of these training tools is objective evidence that firstly, these specific tasks are related to superior sprint performance and, secondly, these methods are suitable for each individual athlete regardless of their current physical power and sprinting performance capabilities.

Finding training strategies that mimic sprint conditions in a specific manner that enables maximum transfer to competition performance is of paramount importance to any coach or physical conditioner. Resisted sled towing has been suggested as the most appropriate training technique to improve the strength of the muscles that contribute to sprinting (Saraslanidis, 2000). It is clear that acute alterations in sprint kinematics occur as a result of resisted sled towing (Letzelter et al., 1995; Lockie et al., 2003). Kinematics such as stride frequency and stride length decrease, where as stance time, trunk and hip angles increase as a consequence of resisted sled towing (Letzelter et al., 1995; Lockie et al., 2003). By increasing the load, a more dramatic change in running technique is often induced, resulting in a slower running velocity. It has been suggested that athletes should not be slowed down by more than 10% during resisted sprint training (Jakalski, 1998). Perhaps, strength ability determines the most appropriate load to use that will not alter running technique too dramatically. It is plausible that particular loads may require a certain level of strength and power in order for the appropriate training stimulus to be achieved.

Little or no information is available on the physical pre-requisites that are required to perform resisted sled training appropriately. These physical pre-requisites need to be identified, together with the minimum muscular qualities (force/power) and/or loads an individual may need, in order to successfully perform resisted sled towing. Furthermore, greater knowledge is vital on whether or not the associated pre-requisites required for resisted sled sprinting are similar to that of unresisted sprinting. There is a paucity of published research into the relationship of strength and power measures to functional performance particularly sprint performance. Abernethy and colleagues (1995) believed this to be reflective of the low priority given to publishing research of this nature by editors and researchers. However, such research is essential as it allows predictors of functional performance to be identified, which aid talent identification, programme development and may provide direction for mechanistic research.

The majority of research studies that have examined the relationships between leg power and sprint ability have often used vertical or horizontal jump displacements as an indirect power measure with correlations ranging from r = 0.44 – 0.77 (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983; Nesser et al., 1996). However, Bradshaw and Le Rossignol (2004) reported that the use of vertical height measures to gauge performance level in gymnasts was inadequate. In fact, of the few studies which have used more sensitive measures such as force and power developed during the jump task; all have reported stronger correlations with sprint performance. For example, Liebermann and Katz (2003) reported a very strong correlation between the mean peak power during a countermovement jump (CMJ) and 20 m sprint time (r = -0.88) whereas other researchers have reported correlations ranging between r = 0.44 – 0.70 for CMJ jump height ability and sprint velocity of the acceleration phase (0 to 30m) (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983), and maximum sprinting speed (r = -0.77) (Young et al., 1995). Additionally, Young, McLean and Ardagna (1995) reported a much stronger linear relationship between the maximum force developed during a weighted squat jump (SJ) and sprint time to 2.5 m (r = -0.86) than the correlation reported between SJ height and starting block leaving velocity (r = 0.63) by Mero, Luhtanen, and Komi (1983). Therefore, identifying the predictive ability of more sensitive kinetic measures with sprint performance from various types of jump assessments warrants further research.

Understanding resisted sled and jump training methods will better assist training prescription for track coaches, conditioners and athletes alike. The purpose of this research was to identify the physical pre-requisites for resisted and unresisted sprint acceleration performance from a block start.

Method

Participants

Ten male (mean ± *SD:* age 20 ± 3 years; height 1.82 ± 0.06 m; weight 76.7 ± 7.9 kg; 100 m personal best: 10.87 ± 0.36 s {10.37 – 11.42 s}) track sprinters at a national and regional competitive level participated in the current study. Each participant gave written informed consent to participate in this study prior to testing. Ethics approval was obtained for all testing procedures from the university ethics committee.

Procedure

Sprint session

Testing was conducted at an IAAF accredited athletic stadium with a Mondo track surface. Each athlete completed their own individual warm-up under the supervision of their coach. The athletes were then asked to perform twelve 10 m sprints from a block start under three experimental conditions. The conditions used were unresisted sprinting and resisted sprinting with two different loads (10% body mass and 20% body mass). The loads tested were selected based upon what was frequently used by the coaches of these athletes. A metal sled weighing 7 kg was employed in this study (see Figure 5.1). A nylon rope 30 m in length was used to connect to the sled and a waist harness that the athlete wore. This rope length was selected as it generated an angle of pull to be relatively close to horizontal (1 - 2°), as calculated using the trigonometric relationship of the sine: sin A = opposite side/ hypotenuse, where opposite side is the height of the athletes hips in the starting blocks and the hypotenuse is the 30 m rope length (see Figure 5.2). The 30 m rope length also enabled a sufficient deceleration distance after the 10 m sprint for the athlete, without the sled crashing into the starting blocks. All experimental conditions were allocated randomly to each participant in order to minimize testing bias. The placement of the starting blocks was individually set according to the preference of the athlete. An experienced starter was used to provide standard starting commands to the athletes. The sprints were separated by a 2 - 3 minute rest period to ensure sufficient recovery. Athletes performed sprints in tight fitting clothing and track spike shoes. The two fastest trials were averaged and used in the data analysis.

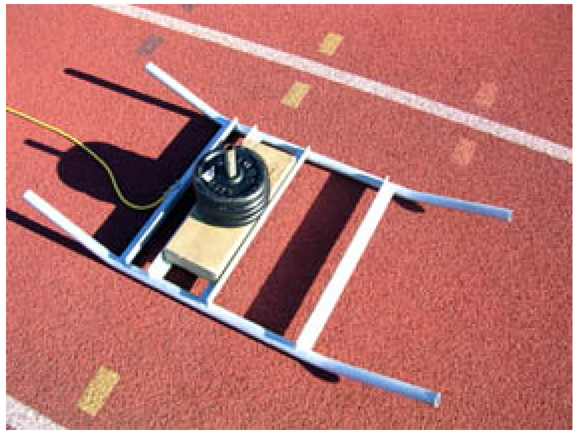


Figure 5.1. Metal sled used for resisted sled towing.

Figure 5.2. The attachment of the sled to the athlete in the starting blocks.

Jump session

Prior to jump data collection anthropometric testing was conducted by an ISAK (International Society for the Advancement of Kinanthropometry) level 2 anthropometrist. Physical dimensions of height, mass, shoulder width (biacromial), hip width (biiliocristal), femur length (trochanterion-tibiale laterale), tibia to floor length (tibiale laterale), and tibia length (tibiale mediale-sphyrion) were measured according to the ISAK international standards for anthropometric assessment. After anthropometry testing each athlete completed their own individual warm-up under the supervision of their coach.

Five types of jump assessments with three test trials were performed by each athlete; squat jump (SJ), countermovement jump (CMJ), continuous straight legged jumps (series of 5 jumps; CJs), single leg hop for distance, and single leg triple hop for distance, all of which have been used extensively in the literature (Arteaga et al., 2000; Bradshaw & Le Rossignol, 2004; Kukolj et al., 1999; Markovic et al., 2004; Mero et al., 1983; Nesser et al., 1996; M. D. Ross et al., 2002; Young et al., 1995). For the SJ the athlete started with their hands on their hips. They were then instructed to sink and hold a knee position (approximately 120^o knee angle), and the experimenter then counted out four seconds (see Figure 5.3). On the count of four the athlete was instructed to then jump as high as possible. A successful trial was one where there was no sinking or countermovement prior to the execution of the jump. The CMJ assessment required the athlete to start with their hands on their hips. They were then instructed to sink as quickly as possible and then jump as high as possible in the ensuing concentric phase (see Figure 5.4). The CJs involved a series of approximately five jumps with straight knees using the ankles to jump (see Figure 5.5). Athletes were permitted to hold their arms loosely by their side during the CJs test, but not use an arm swing to aid the jumps. Instructions were to jump for maximum height and to minimize their contact times in between jumps. The single leg hop for distance required the athlete to begin standing on the designated testing leg with their toe in front of the starting line, and their hands on their hips. Athletes were instructed to sink as quickly as possible and then jump as far forward as possible and land on two feet. For the single leg triple hop for distance athletes began by standing on the designated testing leg with their toe in front of the starting line and hands on their hips. The athletes were instructed to take three maximal jumps forward as far as possible on the testing leg and land on two legs of the final jump. Participants were given the option of 1 - 2 practice jumps, if required, before the specific jump test was conducted. No familiarization session was performed prior to jump testing as a high degree of reliability can be achieved without the need to perform familiarisation sessions for vertical jump assessment (Moir et al., 2004). Plus, most of the jumps used in the study are exercises commonly utilised in the athlete's training regimes. The jumps were separated by a 1 - 2 minute rest period to ensure sufficient recovery. Athletes performed jumps in comfortable clothing and running shoes. All trials were averaged and used in the data analyses.

Data Collection

Swift timing lights (80Hz) were utilized to record the time from the start signal to when the athlete reached the 10 m line and broke the double beam of the timing lights.

A microphone attached to a wooden start clapper was connected to the timing light handset which triggered when the appropriate sound threshold was broken. A portable Kistler Quattro force plate (see Figure 5.6) operating at 500Hz was used to assess leg power for all vertical jumps. Horizontal jump assessments for distance were performed into a jump sandpit.

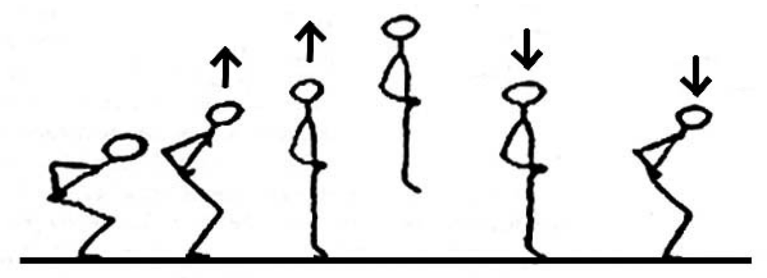


Figure 5.3. Squat jump sequence

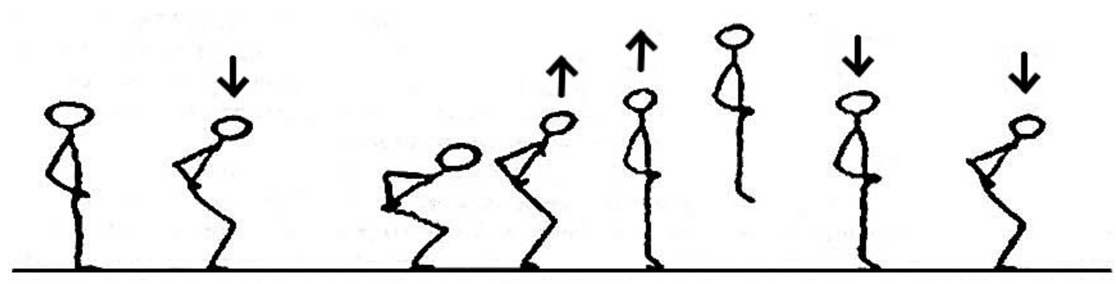


Figure 5.4. Countermovement jump sequence

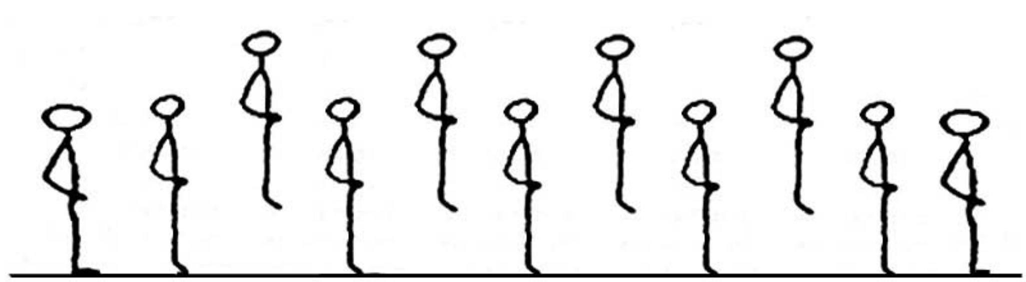


Figure 5.5. Continuous straight legged jump (5 jumps) sequence

Figure 5.6. Portable Kistler Quattro force plate

Data Analysis

Force-time curves of the SJ, CMJ, and series of five straight leg jumps (CJs) were analysed to determine the vertical displacement, peak and average take-off force, ground contact time (for the CJs only), and peak and average take-off power (Kistler software, Switzerland & Microsoft Excel 2000, USA). The athlete's bodyweight was subtracted from the force-time curve. The force-time curve was then integrated with respect to time to obtain the vertical take-off impulse. Vertical take-off velocity, vertical jump displacement, and power were then calculated as:

$$\boldsymbol{v} = \boldsymbol{I}/m$$

$$h = \boldsymbol{v}^2/2g$$

$$\boldsymbol{P} = \boldsymbol{F}\boldsymbol{v}$$

Where $\boldsymbol{v}$=vertical velocity at take-off (m.s^{-1}), $\boldsymbol{I}$ =vertical take-off impulse (N.s), m=body mass (kg), h=peak displacement of the centre of gravity above the height of take-off (m), g=gravitational constant of -9.81 (m.s^{-2}), $\boldsymbol{P}$=power (W), and $\boldsymbol{F}$=force (N). Jump power was calculated for the concentric phase, when velocity was positive until take-off. Peak force was defined as the highest vertical force reading for the take-off movement force curve. All force and power values were normalized to the athlete's body weight (BW and W/kg), respectively.

Statistical Analysis

Means and standard deviations were calculated for each variable. A stepwise linear regression analysis was used to determine the best predictors of four separate dependant variables (a) 100 m personal best sprint time, (b) 10 m sprint performance, (c) 10 m sprint performance with a 10% body mass load, and (d) 10 m sprint performance with a 20% body mass load. The data from a minimum of five to ten participants is required for each predictor measure in a linear equation for statistical strength (Howell, 1992). Therefore, a maximum of two predictor variables that had a statistically significant linear relationship with the dependant variable was utilised in these predictor equations. A linear regression analysis was used to quantify the relationships between the dependant variables and selected anthropometrical, force and power independent variables. The predictive strengths of each variable were ranked according to the product of the regression coefficient – beta (β) and the standard deviation for repeated measurements of each variable. The slope of the regression line is known as the regression coefficient beta (β) (i.e. straight line equation is $y = \beta X + a$ where y = outcome measure, X = predictor measure, and a = the constant intercept). The regression coefficient beta indicates the amount of difference (increase or decrease) in the outcome measure (y) with a one-unit difference in the predictor measure (X) (Howell, 1992). Pearson's product-moment correlation coefficient was also used to establish relationships between dependent variables for both the group and for individual responses. Data from the three fastest trials was used for the individual response analysis. Furthermore, Pearson's product-moment correlation coefficient was also used to establish relationships between independent variables. Statistical significance was set at $p < 0.05$ for all analyses. The number of statistical tests that would be likely to return a significant result by chance alone (Type 1 error) can be calculated by calculating the alpha level by the total number of tests conducted (Hunter et al., 2004a). It is possible that 1 returned significant result would likely have occurred by chance alone due to 25 statistical tests being conducted (i.e. 0.05 x 25). All statistical procedures were performed using SPSS for windows (version 11.5).

Results

The results for all sprint, anthropometrical and jump measures can be observed in Table 5.1. 100 m personal best sprint times ranged from 10.37 s to 11.42 s. Sprint times for the early acceleration sprint (10 m) ranged from 1.94 s to 2.14 s. Sprint performance with a load of 10% body mass was revealed to have the weakest relationship ($r = 0.41$, $p = 0.244$) with unresisted 10 m sprint performance. Performance with a 20% body mass load produced the strongest relationship ($r = 0.65$, $p = 0.041$) with unresisted sprint performance.

Table 5.1. Means ± standard deviations, minimums and maximums for sprint performance, anthropometrical, and jump performance measures.

Parameters	Mean ± *SD*	Minimum	Maximum
Sprint performance measures			
100m PB (s)	10.87 ± 0.36	10.37	11.42
10m no resistance (s)	2.04 ± 0.06	1.94	2.14
10m resisted 10% BM (s)	2.20 ± 0.04	2.15	2.26
10m resisted 20% BM (s)	2.33 ± 0.05	2.24	2.38
Anthropometrical measures			
Shoulder width (cm)	41.1 ± 2.1	37.6	44.2
Hip width (cm)	27.6 ± 1.5	26.1	30.9
Femur length (cm)	44.4 ± 2.0	41.2	47.4
Tibia to floor length (cm)	49.2 ± 3.7	44.4	56
Tibia length (cm)	40.5 ± 1.8	38.5	44.5
Squat Jump measures			
Height (cm)	52.9 ± 4.6	47.2	61.37
Average power (W/kg)	28.44 ± 3.72	22.83	33.73
Peak power (W/kg)	60.57 ± 5.73	51.13	68.54
Average force (BW)	1.04 ± 0.28	0.61	1.5
Peak force (BW)	1.81 ± 0.46	1.07	2.72
Countermovement jump measures			
Height (cm)	57.24 ± 7.87	49.97	76.33
Average power (W/kg)	34.74 ± 3.35	30.63	40.13
Peak power (W/kg)	61.98 ± 5.23	55.09	70.21
Average force (BW)	1.15 ± 0.17	0.98	1.52
Peak force (BW)	1.60 ± 0.23	1.41	2.13
Continuous jump measures			
Height (cm)*	40.36 ± 6.82	25.9	45.47
Average power (W/kg)*	46.10 ± 8.21	30.5	54.2
Peak force (BW)*	5.87 ± 0.97	4.69	7.12
Contact time (ms)*	199 ± 31	167	249
Stiffness (kN/m)*	31.42 ± 10.10	16.45	48
Single leg hop for distance			
Block front leg (m)	2.090 ± 0.090	1.991	2.255
Block back leg (m)	2.096 ± 0.099	1.986	2.269
Single leg triple hop for distance			
Block front leg (m)	6.900 ± 0.205	6.676	7.297
Block back leg (m)	6.903 ± 0.402	6.309	7.526

Note: * = average across five jumps

Table 5.2. Linear regression predictors of 100 m sprint personal best time. All models are statistically significant (p<0.05).

Rank	Predictor	Pearson correlations			Linear regression			
		r	r^2	*p*value	β	β x SD	SEE	%SEE
1	Countermovement jump peak power (W/kg)	-0.86	0.74	0.003	-0.059	-0.308	0.20	2
2	Squat jump peak force (BW)	-0.80	0.63	0.011	-0.623	-0.284	0.23	2
3	Age (years)	-0.74	0.54	0.015	-0.086	-0.268	0.26	2.5
4	Countermovement jump average power (W/kg)	-0.70	0.49	0.037	-0.074	-0.248	0.27	2.5
5	Single leg hop: front block leg (m)	-0.70	0.49	0.039	-2.736	-0.248	0.27	2.5
6	Squat jump peak power (W/kg)	-0.70	0.49	0.037	-0.043	-0.246	0.27	2.5
7	Single leg hop: back block leg (m)	-0.69	0.47	0.040	-2.487	-0.246	0.28	2.5

Table 5.3. Linear regression predictors of 10 m sprint performance. All models are statistically significant (p<0.05).

Rank	Predictor	Pearson correlations			Linear regression			
		r	r^2	*p*value	β	β x SD	SEE	%SEE
1	Countermovement jump average power (W/kg)	-0.79	0.63	0.011	-0.015	-0.05	0.04	2
2	Countermovement jump average force (BW)	-0.78	0.61	0.013	-0.285	-0.049	0.04	2
3	Countermovement jump peak power (W/kg)	-0.77	0.59	0.016	-0.009	-0.047	0.04	2
4	Squat jump peak power (W/kg)	-0.73	0.53	0.026	-0.008	-0.046	0.05	2.5
5	Squat jump average power (W/kg)	-0.72	0.52	0.028	-0.012	-0.045	0.05	2.5
6	Countermovement jump peak force (BW)	-0.70	0.50	0.035	-0.194	-0.044	0.05	2.5

Predictors of 100 m sprint performance

Jump measures that were revealed as significant predictors of 100 m personal best time are summarized in Table 5.2. Linear regression modeling revealed that, for example, an increase of 1 W/kg (2%) in peak power generated during a countermovement jump produced a 0.05 s (0.5%) faster 100 m sprint time. An increase in squat jump peak force by 0.1 Body weight (BW) (6%) was revealed to result in a 0.06 s (0.5%) faster 100 m time. Linear regression analysis also revealed that an increase of 10 cm (5%) in single leg hop distance on either leg would decrease 100 m time by 0.25 s (2%).

Stepwise linear regression analysis was conducted to determine the best predictive measures (out of 25) for the outcome measure of 100 m personal best time. The best linear model was revealed to include countermovement jump take-off power and the anthropometric measure of tibia to floor length, as outlined below:

$$\text{100 m Personal Best Time (s)} = 18.075 - 0.08 \text{ CMJ Peak Power (W/kg)} - 0.045 \text{ Tibia to Floor Length (cm)}.$$

$$r = 0.94,\ r^2 = 0.88,\ p \leq 0.01.$$

Predictors of 10 m sprint performance

The highest ranked predictive test of 10 m sprint performance was the countermovement jump kinetics, as shown in Table 5.3. An increase in countermovement jump average and peak take-off power of 1 W/kg (10% & 5.5% respectively) were both predicted to result in a decrease of 0.01 s (0.5%) in 10 m sprint performance. Further, an increase in countermovement jump average force by 0.1 BW (9%) was predicted to result in a faster 0.03 s (1.5%) 10 m sprint time.

The strongest overall linear model that predicted 10 m sprint performance further attested to the strength of the countermovement jump test as a critical measure. The model can explain 63% of 10 m performance variability and is outlined below:

$$\text{10 m Sprint time (s)} = 2.554 - 0.015 \text{ CMJ Average Power (W/kg)}$$

$$r = 0.79,\ r^2 = 0.63,\ p \leq 0.01.$$

Predictors of 10 m sprint performance with a 10% body mass load

Linear regression analysis revealed, as shown in Table 5.4, that only one jump test was significantly related to 10 m sprint performance with a 10% load. Specifically, the kinetic characteristics of the continuous straight leg jump series was the key predictive measure. An increase in average power by 3 W/kg (6.5%) during the straight legged continuous jumps would result in a decrease of 0.01 s (0.5%) for 10 m sprint performance with a 10% body mass load.

The predictive equation developed from stepwise multiple regression again revealed that performance during the straight legged jump series was the best predictor of 10 m sprint performance with 10% resistance, accounting for 75% of performance variability, as outlined below:

$$\text{10 m sprint time with a 10\% load (s)} = 2.376 - 0.031 \text{ CJs peak force (BW)}$$

$$r = 0.87,\ r^2 = 0.75,\ p \leq 0.01.$$

Predictors of 10 m sprint performance with a 20% body mass load

Linear regression modeling revealed a decrease of 0.01 s (0.5%) for 10 m sprint time with a 20% body mass load could be achieved either by a decrease in continuous jump contact time by 10 ms (5%) or an increase in squat jump average power by 1 W/kg (3.5%) (see Table 5.5).

The strongest overall linear model that predicted 10 m sprint performance with a 20% body mass load included the average ground contacts between jumps of the continuous straight legged jump series and the anthropometric measure of tibia length. The model can explain 86% of the variability of 10 m performance with a 20% body mass load and is outlined below:

$$\text{10 m sprint time with a 20\% load (s)} = 0.001 \text{ CJs ground contact time (ms)} + 0.012 \text{ Tibia length (cm)} + 1.615$$

$$r = 0.93,\ r^2 = 0.86,\ p \leq 0.01.$$

Table 5.4. Linear regression predictors of 10 m sprint performance with a 10% body mass load. All models are statistically significant (p<0.05).

Rank	Predictor	Pearson correlations			Linear regression			
		r	r^2	$p$value	β	β x SD	SEE	%SEE
1	Continuous jump peak force (BW)*	-0.87	0.75	0.002	-0.031	-0.03	0.02	1
2	Continuous jump average power (W/kg)*	-0.83	0.68	0.006	-0.003	-0.025	0.02	1

Note: * = average across five jumps

Table 5.5. Linear regression predictors of 10 m sprint performance with a 20% body mass load. All models are statistically significant (p<0.05).

Rank	Predictor	Pearson correlations			Linear regression			
		r	r^2	$p$value	β	β x SD	SEE	%SEE
1	Squat jump average power (W/kg)	-0.74	0.54	0.024	-0.01	-0.037	0.04	2
2	Countermovement jump average force (BW)	-0.68	0.46	0.044	-0.193	-0.033	0.04	2
3	Countermovement jump peak force (BW)	-0.68	0.46	0.046	-0.145	-0.033	0.04	2
4	Continuous jump contact time (ms)*	0.81	0.65	0.009	0.001	0.031	0.03	1

Note: * = average across five jumps

Discussion

Resisted sled towing is a sprint specific training method employed by many coaches and conditioners in an attempt to improve the sprint acceleration ability of their athletes. Whilst resisted sled towing is a common practice there is no literature that offers any guidelines for the physical pre-requisites required to perform resisted sled towing appropriately. The purpose of this research was to identify the anthropometric and power pre-requisites for resisted and unresisted sprint acceleration performance.

First, the insignificant relationship between unloaded sprinting and resisted sprinting with a sled load of 10% body mass revealed that using a load of 10% body mass may be insufficient to cause the desired training stimulus. Hence the load of 20% body mass may be more appropriate as a significant relationship was discovered between unloaded sprinting and this resisted sprint condition. Whilst this finding can be generalized across sprint athletes, some of the individual responses which were discovered in the reference data (see Table 5.6) indicate that some athletes may benefit more from using a lighter load such as 10% body mass. Specifically the two slowest athletes were revealed to show stronger correlations between their unresisted sprint times and their 10% body mass resisted sprint times ($r = 0.94 – 0.98$), compared with the correlations between their unresisted sprint times and their 20% body mass resisted sprint times ($r = 0.50 – 0.87$). A possible reason for this occurrence could be the limited force production capabilities that these athletes possess. It has been shown in sprinters that greater force production capabilities determine a superior sprint running ability (Mero, 1988; Mero et al., 1983). Intuitively, a greater load (20% body mass) would require the production of a greater force to overcome the inertia of the object. Slower sprinters may be limited in their ability to produce adequate force in order to sufficiently overcome the inertia of the heavier (20% body mass) load quickly whilst sprinting. For the purposes of providing training guidelines for track coaches, the findings of the current study suggest that a resisted sled load of 10% body mass would be a better choice for sprint athletes who complete a 10 m sprint from a block start in greater than 2.10 s. Therefore, sprinting faster than this time can be considered a pre-requisite for using a load of 20% body mass during resisted sled training.

Table 5.6. Reference data for all subjects' sprint times with and without load, and the individual responses between loads.

Rank	10m sprint time no resistance (nr) (s)	10m sprint time 10% BM resistance (s)	10m sprint time 20% BM resistance (s)	Pearson correlations nr&10% r	nr&20% r
1	**1.94 ± 0.02**	**2.16 ± 0.02**	**2.24 ± 0.01**	**0.98**	**0.96**
2	**1.98 ± 0.00**	**2.21 ± 0.02**	**2.30 ± 0.00**	**1.00**	**1.00**
3	2.02 ± 0.03	2.17 ± 0.02	2.32 ± 0.04	0.99	1.00
4	2.02 ± 0.02	2.21 ± 0.01	2.37 ± 0.03	0.50	0.98
5	2.05 ± 0.01	2.22 ± 0.01	2.39 ± 0.04	0.50	0.82
6	2.05 ± 0.02	2.26 ± 0.01	2.39 ± 0.05	0.87	1.00
7	2.06 ± 0.02	2.16 ± 0.02	2.29 ± 0.03	1.00	0.76
8	2.08 ± 0.02	2.24 ± 0.02	2.31 ± 0.02	0.85	0.96
9	**2.11 ± 0.01**	**2.20 ± 0.03**	**2.36 ± 0.01**	**0.94**	**0.50**
10	**2.14 ± 0.01**	**2.26 ± 0.05**	**2.39 ± 0.03**	**0.98**	**0.87**

Performing resisted short sprints increased an emphasis on explosive ability of the lower leg. The continuous jump assessment revealed the best measures (peak force and contact time) that predicted resisted sprinting with a sled. It is not surprising that this jump test elicits the best predictors. Suggested benefits of resisted sled towing are an increase in muscular force output of the lower body (Saraslanidis, 2000), and the develop of specific recruitment of fast-twitch muscle fibers (Lockie et al., 2003) all qualities similar to that of a continuous jump series.

During ground contact (stance phase) of acceleration phase sprinting it is important to produce large propulsive forces in a short time. This is often refereed to as an active ground contact. This activeness refers to the greater percentage of propulsive or active movement during stance in comparison with the braking movement. Ground contact times during unresisted acceleration phase sprinting have been reported to be 193 ms in duration for male sprinters (Mero, 1988), and have also been reported to be strongly related ($r = -0.65$) to unresisted acceleration phase velocity (Mero et al., 1983). There is no question that resisted sled towing increases ground contact time (Letzelter et al., 1995; Lockie et al., 2003), and it can be assumed that an increase in resistance would require more force production in order to overcome the inertia of the loaded sled. In fact, it was suggested by Lockie and colleagues (2003) that greater muscular power to overcome the resistance required an increase in ground contact time. Therefore, the ability to produce large propulsive forces is critical for the athlete in order to overcome the sleds inertia, while still minimizing ground contact time, especially as load increases. The findings of the current study suggest that in order to perform resisted sled towing appropriately, the ability to perform continuous straight legged jumps explosively and with minimal ground contact time between jumps is critical.

In nearly all instances power measures from the vertical jump assessments were revealed to be the best predictors of unresisted 10 m sprint time and 100 m personal best time. This indicates the importance of power production from the leg musculature in sprint performance. Specifically, countermovement jump measures often produced the best indication of free running sprint ability. This jump assessment is performed with a rapid stretching of the lower limb musculature which is also contracting at a high velocity. This suggests that an athlete's relative explosive ability of their hip and knee extensors is critical to sprint performance. In fact the stored energy from the elastic properties of the muscle has been suggested to be necessary to sprint performance (Mero et al., 1992). Many studies have found a relationship between countermovement jump measures and sprint performance. Correlations ranging from r = 0.48 - 0.70 have been reported between countermovement jump performance and the velocity produced during the early acceleration phase when sprinting (Bret et al., 2002; Kukolj et al., 1999; Mero et al., 1983). These relationships provide further evidence suggesting that explosive leg power is an important aspect of sprint performance, especially during the early acceleration phase. It is recommended that the countermovement jump be considered as a training exercise to improve acceleration performance.

Interestingly the triple hop for distance was not identified as a predictor of any of the sprint times. This jump assessment is cyclic in nature (multiple expression of power) and performed horizontally similar to that of sprint running it is perplexing as to why no relation was discovered. Nesser and colleagues (1996) reported a very strong relationship (r = 0.81) between a horizontal 5-step jump and 40 m sprint time. The participants of the study of Nesser and colleagues (1996) were involved in sports that required short expressions of straight sprint and agility type movements, where as track sprinters whom run one direction in a straight line were utilised in the current study. This suggests that there may be no homogeneous relationship between cyclic horizontal jumps and sprint performance. It also suggests that horizontal cyclic jump assessments are better suited for athletes competing in sports that involve multiple direction movement. Possibly three hops are insufficient to reveal a relationship with sprint performance. Perhaps the preconception to use distance as a performance measure is invalid when attempting to identify the predictability of this triple hop measure to sprint performance. Perhaps more sensitive measures such as average power and average force produced during the hops would better reflect what is occurring. This was made evident in the vertical jumps with force and power measures being better predictors of sprint performance than height only in the current study. The use of vertical height measures to gauge performance level in gymnasts has been shown to be inadequate (Bradshaw & Le Rossignol, 2004). It is acknowledged that access to more advanced dynamometry would be required and field tests are more appropriate to administer, but with the advancement of technology into portable equipment it may be more appropriate to utilise these types of devices to better gauge the athletes ability.

Conclusion

A key quality that indicated the athletes unresisted 10 m and 100 m sprint performance was the relative explosive ability of the sprinters hip and knee extensors during the countermovement jump. Coaches of track athlete's should consider the countermovement jump as a training exercise to improve both 10 m and 100 m sprint performance. For the coach intending on employing resisted sled towing in their athlete's training regime a load of 20% body mass would be the most appropriate, especially for athletes who sprint 10 m from a block start in less than 2.10 s. However, athletes unable to acquire this sprint time may benefit more from a load of 10% body mass during resisted sled sprints. When deciding to graduate the athlete to using a load of 20% body mass the ability to perform well during the continuous straight legged jump is the best pre-requisite due to its relationship with fast propulsive foot plants during the early strides of resisted sled towing. Future research directions should include the monitoring of the identified qualities of these sprinters with training in the long term, and identifying anthropometric and power predictors for the other phases of short sprint running.

CHAPTER SIX

Discussion and Conclusion

The inspirations of the modern Olympic era are notably the champions of the athletics track and field, the swimming pool, the cycling velodrome and road, and the gymnastics hall. Champion athletes in all of these Olympic pursuits (and others) push the capabilities of the human body in order to achieve their performance goal. On the track the sprinters encompass power and speed, together with near-flawless technical form. To earn a lane in the Olympic final (1 of 8) they must psychologically and physically defeat a large field of competitors from their home country and abroad. The road towards that moment in a champion's career is long and grueling. To reach this level of competition an athlete must train well above ten thousand hours on and off the athletics track over a period of ten to fifteen years, pursuing an arduous sequence of competition levels and personal goals. It is this psychological and physical accomplishment that attracts the interest and passion of sports scientists.

Hundreds of scientific studies have examined the short sprint events to understand the technical aspects of this pursuit. Biomechanists, for example, have over a time span of several decades achieved an adequate technical description of the sprinting action during the sprint (block) start, acceleration, maximal velocity, and deceleration phases. However, little information to the author's knowledge is known on the technical and power training strategies appropriate to use to enhance an athletes sprint start and early acceleration (10 m) ability.

The first 10 m in competitive sprint running has been advocated as the most critical distance covered during short sprint races, especially for the 100 m sprint event (Ae et al., 1992; Coh et al., 1998; Ferro et al., 2001; Harland & Steele, 1997; Moravec et al., 1988; Muller & Hommel, 1997). Therefore, identifying training strategies to improve sprint performance over this distance is of paramount importance. Training interventions such as technical training, weight training, plyometric training, and resisted sled training are all utilised in an attempt to improve the athlete's strength and power. Greater force production during sprint running and consequently a faster sprint performance are the supposed transfers from the increases in strength and power. However, many training strategies employed by coaches and conditioners to enhance sprint start and early acceleration performance have no solid empirical evidence to support claims that they improve sprint performance. Furthermore, few studies have attempted to examine the effects and appropriateness of various training strategies on sprint start and early acceleration performance. Identifying and understanding the training determinants of sprint start and early acceleration performance would allow for optimal training strategies to be prescribed for track sprinters.

The results of this thesis indicated that a key predictor of a sprinter's unresisted 10 m and 100 m sprint performance was the relative explosive ability of their hip and knee extensors, as seen during the countermovement jump. This finding supports the contention that jump training is a useful training strategy for improving early acceleration performance (Delecluse et al., 1995; Mero et al., 1983; Rimmer & Sleivert, 2000; Young, 1995).

Sprint start block performance (mean horizontal block acceleration) was revealed as one of the key kinematic predictors of 10 m sprint time in this thesis. This finding further emphasised the importance of a good block start which has been advocated as a critical aspect to the final outcome of a short sprint (Ae et al., 1992; Coh et al., 1998; Ferro et al., 2001; Harland & Steele, 1997; Moravec et al., 1988; Muller & Hommel, 1997). The simplistic appearance of a well executed sprint (block) start is quite deceptive. The complex nature of this task requires a sprint athlete to generate large horizontal forces against the blocks in order to produce a large horizontal leaving velocity out of the starting blocks in the shortest time possible (Harland & Steele, 1997; Helmick, 2003; Mero, 1988; Mero et al., 1983). Results of this thesis revealed mean horizontal block velocity and start time to both be key kinematic predictors of mean horizontal block acceleration (sprint start performance). This suggests an interaction between mean horizontal block velocity and start time with an optimal combination of these factors being required to maximize sprint start (block) performance. Therefore, sprinters should focus their block start training on producing a large horizontal block velocity over a short period of time with slightly more emphasis being placed on producing a large horizontal velocity. The generation of a larger block impulse (force x time) which may be achieved by a more pronounced horizontal thigh angle of the front block leg at takeoff from the blocks will lead to a large horizontal velocity according to the impulse-momentum relationship.

Resisted sled towing appears to be an excellent training tool for improving sprint start (block) ability, due to the fact that such training can increase the horizontal force output within the starting blocks without a significantly detrimental affect on sprint start kinematics. Although sprint start performance (mean horizontal block acceleration) was not negatively affected as a result of resisted sled towing, two vital sprint start kinematics, start time and block push-off angle were stimulated. A resisted sled load of 20% body mass was revealed as the best load to employ to induce a beneficial adaptation. Specifically, this training stimulus allowed the generation of a larger force within the starting blocks, whilst permitting a more horizontal leaving position from the starting blocks, with minimal disruption to technique.

The ability to produce a rapid (more explosive) arm drive and a subsequent greater front upper arm extension during take-off for the first few steps once the athlete departed from the starting blocks was another method identified in this thesis as improving 10 m sprint time. Consideration should therefore be given to improving these upper body kinematics once the athlete has left the starting blocks. These technical aspects of training should be used in conjunction with resisted sled towing to improve sprint performance. Early acceleration sprint kinematics would benefit from a training tool such as resisted sled towing. A load of 20% body mass may be advantageous for improving the athlete's step length through a greater propulsive ability and increased flight phase capabilities which may lead to improved sprint running in the long term. However, athletes who are unable to sprint 10 m from a block start in less than 2.10 s may benefit more from training with a load of 10% body mass during resisted sled sprints. When considering the use of a 20% body mass load the ability to perform well during the continuous straight legged jump is the best pre-requisite. Specifically, measures of peak force and contact time during the continuous jump assessment were identified as the best predictors of sprinting with a load of 20% body mass.

Conclusion

Coaches and sprint athletes should direct much attention to improving the sprint start (block) phase as it is critical to the outcome of a short sprint event. Improved sprint performance can be achieved through the use of training methods such as technical training and resisted sled towing. Technical considerations for maximizing sprint start (block) performance (mean horizontal block acceleration) should be placed on optimizing both the horizontal block velocity and start time. A superior sprint start may be achieved by training the sprinter's ability to achieve a more horizontal thigh angle of the front block leg at block takeoff. Resisted sled towing with a load of 20% body mass will allow greater force production as well as a more horizontal drive out of the starting blocks, which are important aspects of the sprint start.

Therefore this training modality should be employed to improve sprint start performance.

Once the athlete has left the starting blocks and has entered the early acceleration phase (10 m) technical coaching emphasis should be placed on a more explosive arm drive and a subsequent greater front upper arm extension. Resisted sled towing with a load of 20% body mass may lead to future improvements in step length which may lead to improved early acceleration performance. The countermovement jump exercise would be most appropriate to employ for improving both 10 m and 100 m sprint performance.

Further investigation on training strategies for the sprint start and early acceleration sprint running is warranted. Examination of a larger sample or different sample population (e.g. females, junior athletes) to increase the applicability of each experimental chapter's findings within this thesis is required. Future research directions should include an examination of whether training the identified kinematic predictors (e.g. horizontal thigh angle of the front block leg at block takeoff) or power predictors (e.g. countermovement jump, straight leg jump series) lead to an improved sprint start or enhanced sprint running ability. An investigation of the long term adaptations that resisted sled towing may have on both sprint performance and sprint kinematics of the start and early acceleration phases also warrants attention from sport scientists.

References for this chapter are included in the list of references on the last few pages of this thesis.

CHAPTER SEVEN

Coach Applications

Introduction

The challenge of any sports biomechanics research is to gain insight on training and/or technical performance issues that aims to lead towards new recommendations for coaches and athletes. An accompanying task of this thesis was, therefore, to provide training guidelines that would enhance the knowledge of track sprint coaches from all levels and backgrounds on technical and power training strategies for improving sprint start and early acceleration (10 m) performance. The final chapter of the thesis, therefore, was written for an athletic coach audience. However, it must be reiterated that only 10 male sprinters were used in this novel thesis. Therefore additional research is warranted in this area to confirm these findings.

Why train the sprint start and early acceleration phases?

Sprint running research has shown that exceptional sprinters often dominate the sprint start and early acceleration phase (10 m) of the short sprint races. For example, Olympic and World Champion 100 m sprint greats like Maurice Greene had the fastest start and fastest time to a distance of 10 m. Additionally the results of this thesis have indicated that the better sprint starters are also the fastest to a distance of 10 m from a block start. Therefore, it would be in the sprinter's interest to develop their sprint start ability. It is proposed that if sprint athletes concentrate much training effort on the early acceleration and sprint start especially, they will have an advantage in the short sprints.

Note for the Reader

Some of the following tables have been presented in an "Input" (e.g. change in technique) "Output" (e.g. change in performance) sequence ($\text{Predicted Absolute } \Delta X$). Within these sequences, some of the changes are expressed as a percentage change ($\text{Predicted } \%\Delta X$) of that particular measure, which is with respect to the group average ($\overline{X}$) of the athletes tested in this thesis (i.e. $\text{Predicted } \%\Delta X = \dfrac{\text{Predicted Absolute } \Delta X}{\overline{X}} \times 100$).

Technical Training Considerations for Block Start Performance

During technical sprint start training, coaches should encourage their athletes to produce a large horizontal block velocity over a short period of time (quick forceful movement). This may result from a more forceful horizontal push from the upper leg of the front block leg (decreasing the thigh angle with respect to the horizontal) at block takeoff. Table 7.1 illustrates some possible technical inputs for improving block start performance.

Table 7.1. Technical aspects to improve sprint start performance.

INPUT:

- Increasing (↑) mean block velocity by 0.1 $m.s^{-1}$ (~7%)
  Range: 1.3 – 1.6 $m.s^{-1}$ Group Average ± SD: 1.5 ± 0.2 $m.s^{-1}$
- Decreasing (↓) start time (time from reacting to leaving the blocks) by 0.02 s (~6%)
  Range: 0.27 – 0.34 s Group Average ± SD: 0.31 ± 0.03 s
- Decreasing (↓) angle of thigh of the front block leg at block takeoff (more horizontal push) by 3° (~7%)
  Range: 40 – 51° Group Average ± SD: 43 ± 4°

OUTPUT:

- An increase (↑) in mean horizontal block acceleration (sprint start performance) by 0.5 $m.s^{-2}$ (~10%)
  Range: 4.0 – 6.5 $m.s^{-2}$ Group Average ± SD: 4.8 ± 0.9 $m.s^{-2}$

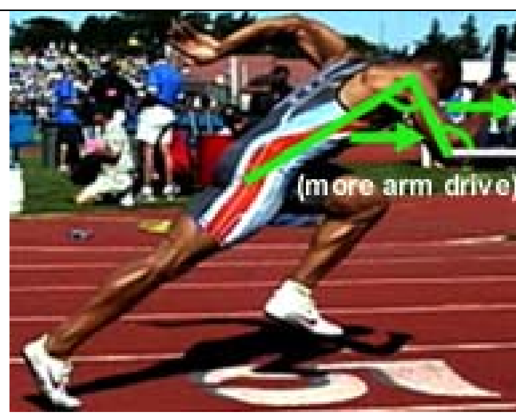
Technical Training Considerations for Early Acceleration (10 m) Performance

It is reiterated that sprint coaches should focus training on improving sprint start performance (mean horizontal block acceleration) as this will lead to a faster 10 m sprint time. Once the athlete has left the starting blocks sprinters should emphasise strong front upper arm extensions (more arm drive) during step takeoff in order to improve 10 m sprinting ability. Therefore sprint coaches should call attention to both increased upper arm segment and shoulder joint angles of the front arm (higher arm position) at step takeoff of their sprint athletes during both training and competition. Below (Table 7.2) are some guidelines of possible changes that may occur to 10 m sprint time from starting blocks when some of the identified key kinematic predictors revealed in this thesis are altered.

Table 7.2. Technical aspects to improve 10 m sprint performance.

INPUT:

- An increase (↑) in mean horizontal block acceleration (sprint start performance) by 0.5 $m.s^{-2}$ (~10%)
  Range: 4.0 – 6.5 $m.s^{-2}$ Group Average ± SD: 4.8 ± 0.9 $m.s^{-2}$
- Increasing (↑) angle of front arm shoulder at step takeoff by 3° (~10%)
  Range: 4– 43° Group Average ± SD: 29 ± 12°
- Increasing (↑) angle of front upper arm at step takeoff by 3° (~4%)
  Range: 29 – 85° Group Average ± SD: 67 ± 17°



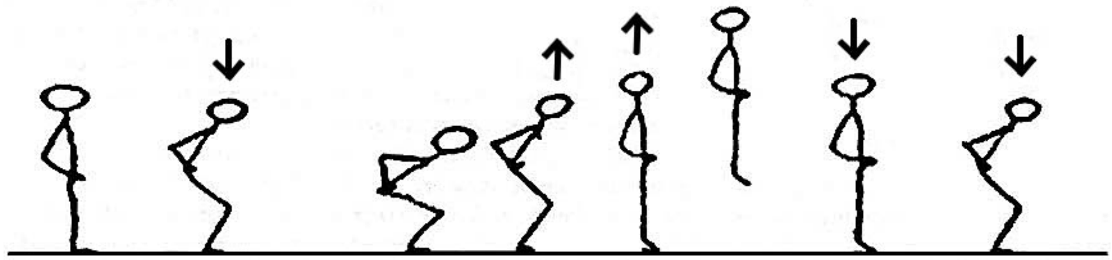
OUTPUT:

- A Decrease (↓) in 10 m sprint time from starting blocks by 0.01 s (~0.5%)
  Range: 1.94 – 2.14 s Group Average ± SD: 2.04 ± 0.06 s

Power Training Considerations for Early Acceleration (10 m) Performance

Power training can be employed to improve sprint running and can play a major role in the development of the sprint athlete. Jump or plyometric training appears to be useful for improving sprint ability. Specifically the force and power production capabilities during the countermovement jump were revealed in this thesis to be strong predictor measures of 10 m sprint time. Hence, track sprinters should consider the countermovement jump as a training exercise to improve 10 m sprint performance. Below (Table 7.3) are some possible outcomes that may occur to 10 m sprint time from starting blocks when some of the identified key jump assessment kinetic predictors revealed in this thesis are altered.

Table 7.3. Power training to improve 10 m sprint performance.



Countermovement Jump

INPUT:

- Increasing (↑) countermovement jump max power by 3 W/kg (~4.5%)
  Range: 55 – 70 W/kg   Group Average ± SD: 62 ± 5 W/kg
- Increasing (↑) countermovement jump average power by 3 W/kg (~4.5%)
  Range: 31 – 40 W/kg   Group Average ± SD: 35 ± 3° W/kg
- Increasing (↑) countermovement jump average force by 0.1 BW (~9%)
  Range: 0.98 – 1.52 BW   Group Average ± SD: 1.15 ± 0.17 BW

OUTPUT:

- A Decrease (↓) in 10 m sprint time from starting blocks by 0.05 s (~2.5%)
  Range: 1.94 – 2.14 s   Group Average ± SD: 2.04 ± 0.06 s

Power Training Considerations for 100 m Sprint Performance

A wider variety of jump exercises appear appropriate to use for improving 100 m sprint performance. In particular the countermovement jump, squat jump and single leg hop for distance assessments should be considered by coaches to improve their athletes sprint ability. Below (Table 7.4) are some guidelines of possible changes that may occur to 100 m sprint performance when the identified key jump assessment kinetic predictors revealed in this thesis are altered.

Table 7.4. Power training to improve 100 m sprint performance.

INPUT:

- Increasing (↑) countermovement jump maximum power by 1 W/kg (~1.5%)
  Range: 55 – 70 W/kg Group Average ± SD: 62 ± 5 W/kg
- Increasing (↑) squat jump maximum force by 0.1 BW (~5.5%)
  Range: 1.1 – 2.7 BW Group Average ± SD: 1.8 ± 0.5 BW
- Increasing (↑) single leg hop for distance on any leg by 2 cm (~1%)
  Range: 199 – 226 cm Group Average ± SD: 210 ± 10 cm

OUTPUT:

- A Decrease (↓) in 100 m sprint time from starting blocks by 0.05 s (~0.5%)
  Range: 10.37 – 11.42 s Group Average ± SD: 10.87 ± 0.36 s

Resisted Sled Training Considerations

Resisted sled towing is an excellent training tool to employ in an individuals training regime to improve sprint start performance or early acceleration performance. A resisted sled load of 20% body mass is an appropriate load especially for athletes who complete a 10 m sprint from starting blocks in less than 2.10 s. However, for athletes who take longer than 2.10 s to reach the 10 m mark, a load of 10% body mass may be more appropriate.

Start Technique Alterations whilst Performing Resisted Sled Towing

A number of sprint start kinematics are altered as a result of resisted sled loading. Specifically, the start time and block push-off angle kinematics are altered and may benefit from the added resistance and lead to an enhancement in overall sprint start performance in the long term. Consideration must be given to the amount of change that can occur to these start kinematics for each load. Below are some approximate changes in start kinematics to expect when utilising resisted sled towing with a load of 10% or 20% body mass.

- Start kinematic percentage changes with a load of 10% body mass.
    - Start time (s) ↑ ~6% (more force)
    - Block push-off angle (°) ↓ ~3% (more horizontal)

- Start kinematic percentage changes with a load of 20% body mass.
    - Start time (s) ↑ ~10% (more force)
    - Block push-off angle (°) ↓ ~4.5% (more horizontal)

Track coaches of sprint athletes should consider resisted sled loading for improving the sprint start as it will allow for a large generation of force within the starting blocks, and cause a more horizontal (forward) leaving position from the starting blocks, whilst causing minimal disruption to technique.

Sprint Running Technique Alterations while Performing Resisted Sled Towing

Not only does resisted sled loading appear useful for improving the sprint start phase but it may be helpful for increasing step length in the long term. During resisted sled training the steps will shorten whilst being performed at a similar turnover rate to that employed during unresisted sprinting. Resisted sled towing may lead to greater active ground contacts (propulsive ability) and increased flight phase capabilities which may improve both step length and sprint running in the long term. Consideration must be given to the amount of change that can occur to these start kinematics for each load. Below are some approximate changes in step kinematics to expect when utilising resisted sled towing with a load of 10% or 20% body mass.

- Step kinematic percentage changes with a load of 10% body mass.
    - Ground contact time (ms) ↑ ~5%
    - Propulsion time (ms) ↑ ~7%
    - Flight time (ms) ~No change
    - Flight distance (m) ~No change

- Step kinematic percentage changes with a load of 20% body mass.
    - Ground contact time (ms) ↑ ~12%
    - Propulsion time (ms) ↑ ~10%
    - Flight time (ms) ↓ ~15%
    - Flight distance (m) ↓ ~25%

Pre-requisites for Performing Resisted Sled Towing

For the coach or athlete unsure on which load to use (10% body mass or 20% body mass) or which loads are better suited for certain sprint athletes, some sprint ability and power pre-requisites are presented below. The ability to perform well during a continuous straight legged jump series (see Figure 7.1) is the best pre-requisite for performing resisted sprinting due to its relationship with fast propulsive foot plants during the early strides of resisted sled towing.

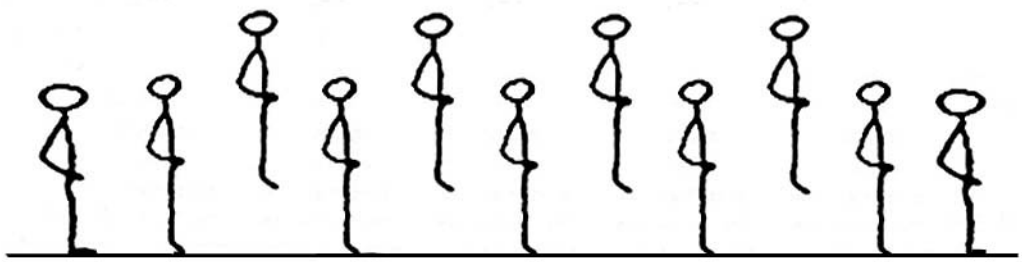


Figure 7.1. Continuous straight legged jump (5 jumps) sequence.

Specifically, in order to benefit from the performance of resisted sled towing with a load of 20% body mass, the athlete should have short contact times between jumps of the continuous straight legged jump (5 jumps) series, large average power production during takeoff of a squat jump, and the ability to generate a great amount of force during the countermovement jump (see Table 7.5).

Table 7.5. Pre-requisites for resisted sled towing with a load of 20% body mass.

Sprint 10 m from a block start	< 2.10 s
Continuous straight legged jump: contact time	< 210 ms
Squat jump: average power	> 28 W/kg
Countermovement jump: average force	> 1 BW

The pre-requisites for performing resisted sled towing with a load of 10% body mass are the athlete's maximal force production capabilities and ability to produce a large average power output during the continuous straight legged jump (5 jumps) series (see Table 7.6).

Table 7.6. Pre-requisites for resisted sled towing with a load of 10% body mass.

Sprint 10 m from a block start	> 2.10 s
Continuous straight legged jump: peak force	> 5 BW
Continuous straight legged jump: average power	> 30 W/kg

Conclusion

Training strategies such as technical, jump, and resisted sled towing appear to be appropriate interventions to employ in a sprinters training regime. If the training goal of the track and field sprints coach or athlete is to improve sprint start performance or early acceleration performance, a combination of these training tools should be employed. However, the manner in which these techniques may be integrated into the annual training plan still requires future research.

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APPENDICIES

Appendix A: Participant Information Sheet

Participant Information Sheet

Project Title: The effects of resisted training on the kinematics of the sprint start

Project Supervisors: Justin Keogh and Dr Elizabeth Bradshaw

Researcher Peter Maulder

Date Information Sheet Produced: 20/02/04

Invitation You are invited to participate in a research study which is being done as part of a Masters Thesis entitled 'The effects of resisted training on the kinematics of the sprint start'. Your participation in this study is completely voluntary and can be declined at any time without you giving a reason or being disadvantaged in any manner. You may also withdraw any information you have provided at any time up until data collection is completed without penalty.

What is the purpose of the study? The purpose of this study is to compare the sprint biomechanics when sprinting with and without towing a sled that weighs 10% or 20% of your body weight.

How are people chosen to be asked to be part of the study? If you are an elite or a sub elite male track sprinter you are eligible to participate in this study.

What happens in the study? Those participating in the study will be asked to attend three testing sessions (one familiarisation session and two testing sessions) each separated by 3-4 days. Prior to all sessions, you will be asked to complete your competition based warm-up. For the familiarisation session, you will be given verbal instructions on how to perform sprint starts with the sled. You will then have the opportunity to perform three trials for each of the three test conditions (no sled, 10%

bodyweight sled, and 20% bodyweight sled) from the starting blocks over a distance of ten metres. The sled will be attached to your waist. For the testing session, after you have completed your competition warm-up you will then be videoed performing three sprint starts with no sled, then three at 10% body mass and a further three at 20% body mass. Rest periods of five minutes will be given between each sprint start test trial.

You will also be assessed for a number of lower body strength and power measures. Specifically, these involve one repetition maximum squat assessments, vertical jumps and horizontal jumps. The squat and vertical jump assessments will be conducted in a Smith Machine located at Auckland University (AUT) of Technology, whereas the horizontal jumps will be conducted after the nine sprints are completed at the Millenium of Institute of Sport and Health (MISH) athletics track.

What are the discomforts and risks? As a participant there will be an element of physical risk in terms of injury. However, this risk is no more than during your normal sprint training programmes.

How will these discomforts and risks be alleviated?
To reduce this risk you will be given the opportunity to perform your normal warm-up you would utilise in competition meetings. An experienced sprint coach will also supervise the sessions.

What are the benefits? All participants will be given an individualised report on their sprint start technique along with possible recommendations for improvements (if needed). The strength / power assessment will also give the athletes some indication of whether the main focus of their training should be to improve their starting technique or their muscular strength and power. This will therefore have implications to their training program design. Participants will also gain an insight into the research process and contribute to the advancement of knowledge regarding elastic cord training and its effects on sprint start performance.

What compensation is available for injury or negligence?
The ACC system, with its limitations, will provide standard cover if participants are injured.

How will my privacy be protected? Information obtained from analysing the video footage will be stored under an identification code and not the participant's name. The primary investigators will be the only people to have access to the coded data and videotapes that will be stored on a password-protected computer and in a locked cabinet, respectively. When presenting the results, you will not be identified.

How do I join the study? If you wish to participate in this study please contact Justin Keogh on 917 9999 x7617 or Peter Maulder on 917 9999 x7119 or 021 045 8877

What are the costs of participating in the project? There are no costs involved in the participation in this study, except your time commitment of two one hour sessions.

Opportunity to consider invitation You will have time to consider your participation in this study. If you have any further questions or would like further information feel free to contact either Justin Keogh on 917 9999 x7617 or Peter Maulder on 917 9999 x7119 or 021 045 8877

Opportunity to receive feedback on results of research If requested a copy of the research report will be available for you to view upon its completion. In addition, you will be given some feedback on how your training technique changed (if at all) and the implications of this for injury prevention and performance enhancement.

Participant Concerns Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Mr Justin Keogh, justin.keogh@aut.ac.nz; phone 9917 9999 ext 7617 or fax 9917 9960. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz , 917 9999 ext 8044.

Researcher Contact Details: Peter Maulder 021 045 8877, 09 917 9999 x7119

Project Supervisor Contact Details: Justin Keogh 09 917 9999 x7617

Approved by the Auckland University of Technology Ethics Committee on May 4 2004 **AUTEC Reference number** 04/35

Appendix B: Consent Form

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Consent to Participation in Research

Title of Project: The effects of resisted training on the kinematics of the sprint start

Project Supervisors: Justin Keogh and Dr Elizabeth Bradshaw

Researcher: Peter Maulder

- I have read and understood the information provided about this research project (Information Sheet dated 20/2/04.)
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all relevant tapes and transcripts, or parts thereof, will be destroyed.
- I agree to take part in this research.
- I wish to receive a copy of the report from the research.

Participant signature:...……………………..
Participant name: ………………………………………………………….
Participant Contact Details (if appropriate):
………………………………………………………………………………………

Date:

Project Supervisors Contact Details:

Justin Keogh	Dr Elizabeth Bradshaw
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Approved by the Auckland University of Technology Ethics Committee on May 4 2004 **AUTEC Reference number** 04/35

Appendix C: Ethics Approval

MEMORANDUM

Student Services Group - Academic Services

To:	Justin Keogh
From:	**Madeline Banda**
Date:	25 March 2004
Subject:	04/35 The effects of assisted and resisted elastic cord training on the kinematics of the sprint start

Dear Justin

Thank you for providing amendment and clarification of your ethics application as requested by AUTEC.

Your application was approved for a period of two years until 25 March 2006.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in <u>all</u> correspondence and telephone queries.

Yours sincerely

Madeline Banda
Executive Secretary
AUTEC
CC: Peter Maulder

Appendix D: Reliability of Jump Measures from Portable Force Plate

During pilot testing the reliability of some of the jump measures attained from the portable force plate were calculated for one subject. Coefficients of variation were calculated for the jump measures using data from three trials of the vertical jump tests.

Squat jump

- Jump displacement (m) CV= 1.7%
- Mean Power (W/kg) CV= 1.3%
- Peak Force (BW) CV= 2.1%

Countermovement jump

- Jump displacement (m) CV= 1.1%
- Mean Power (W/kg) CV= 2.0%
- Peak Force (BW) CV= 2.1%

Continuous straight legged jump

- Jump displacement (m) CV= 1.1%
- Mean Power (W/kg) CV= 2.0%
- Peak Force (BW) CV= 2.1%

Appendix E: Anthropometrical Measures Used in Thesis