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Kinetic and Kinematic Properties of D-I Male Sprinters

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Kinetic and Kinematic Properties of D-I Male Sprinters

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ABSTRACT

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The purpose of the study was to explore and determine kinetic and kinematic variables that related to D-I male sprinters maximal running velocity performance. The current study was separated into 3 individual chapters: 1.) Kinematic analysis magnitude of acceleration for braking and propulsion phases during foot contact phase at maximal speed sprinting; 2.) Using kinetic isometric mid-thigh pull variables to predict D-I male sprinters' 60m performance; 3.) Relationship of whole and lower body angular momentum cancellation during terminal swing phase to sprint performance.

Methods: for sprint measurement all the athletes were participated 2 trials of 100% effort running through 60 meters. The sprint time was measured by an electronic timing gate system. The electronic timing gate system was placed at every 10 meter intervals from the start line for 60 m. Six cameras were placed between 50 m and 60 m for kinematic data collection and analysis. Volume captured by the cameras is 7.5 m long, 1.2 m wide, and 1.95 m high. Reflective markers were attached on the body landmarks based on Vicon Nexus full body plugin model.

The strength assessments were performed in a customized power rack, and kinetic values were collected via a dual force plate setup (2 separate 91 cm x 45.5 cm force plates, Roughdeck HP, Rice Lake, WI). The position for each isometric pull was established before each trial using

goniometry, with each bar height corresponding to a 125±5º knee angle and a near-vertical trunk position.

Results: current study partially support previous assumption that fast sprinters can minimize braking phase during foot contact phase when they are running maximal velocity. However, those minimizing effects did not impact maximal running velocity performance. Second, the study showed that fast sprinters can produce greater force during a short period of time than slower sprinters. Moreover, a certain trend of statistical significance was observed from the third study that angular momentum cancellation between lower bodies at frontal plane may be related to maximal running velocity performance.

Discussion: the current study confirmed that fast sprinters can produce greater force in a short period time. However, the current study did not show statistical significance of angular momenta cancellation and sprint performance. Only a level of trend was observed. Thus, further study should examine sprinters with different training background, especially elite level sprinters is definitely needed.

DEDICATION

I would like to dedicate this dissertation to my parents - Li Sha and Li-nan Wang for their love and support in my life. Also, I would like to dedicate this dissertation to those who pursue the best performance in sprint events and in the field of sports performance.

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CHAPTER 1

INTRODUCTION

Sprint running is divided into three distinct phases based on the velocity–time curve. These are 1) acceleration, 2) maximum velocity, and 3) velocity maintenance phases. However, due to the complexity of the sprint start, some coaches and studies consider sprint start as one single separate phase (Mero, Komi, & Gregor 1992).

This study is focused on maximal running velocity phase and this is discussed in the following context. Biomechanical analyses of sprint performances have been conducted for a long time. From kinematics and kinetics perspectives many factors have been confirmed to relate to sprint performance. However, some questions have not been answered and some assumptions have not been confirmed. For example, more active touch down (foot make contact with ground) movement before foot contact phase (period of time from foot first contact with ground until it leaves the ground) could minimize velocity loss during subsequent foot contact phase in maximal velocity running phase. In addition, the role of kinetic variables (rate of force development, maximal strength) for sprint performance also need to be confirmed. Thus, the current study is focused on 1) Kinematic analysis magnitude of acceleration for braking and propulsion phases during foot contact phase at maximal speed sprinting; 2) Using kinetic isometric mid-thigh pull variables to predict D-I male sprinters' 60m performance; 3) Influence of whole and lower body angular momentum cancellation during terminal swing

1. **Kinematic analysis magnitude of acceleration for braking and propulsion phases during foot contact phase at maximal speed sprinting**

   Elite sprinters have the ability to maintain the maximum velocity, which is a critical factor for the 100 m sprint performance. In addition, elite sprinters do not show significant decreasing of the maximum velocity as compared to the less skilled sprinters in the race. In fact, the five top finalists showed a second peak maximum velocity phase at the end of the 100 m race (Ae, Ito, & Suzuki 1992). The evidence indicated elite sprinters have an excellent anaerobic energy system, neuromuscular system, and better sprint techniques compare to subelite sprinters.

With a force platform being used in evaluation and testing sprint performance, it assists researchers, coaches, and athletes to better understand the cause of movements during the contact phase. After a series of tests for running kinetics by using a force platform, Payne, Slanter, and Telfor (1968) found braking thrust during the early foot contact phase followed by a propulsive thrust later during the foot contact phase. The magnitude of braking force was different based on the different phase (according on the velocity curve) of running. During the first step of the acceleration phase, the braking force was small; and the propulsive force was a large portion of the foot contact phase. During the constant velocity of the running phase, the average of braking and propulsive forces was zero after ignoring air resistance (Payne et al., 1968). Based on their findings (Payne et al., 1968), the authors stated that the smaller the magnitudes of the braking and propulsion forces, the more efficient running becomes. However, Bates, Osterning, and Mason (1979) found that the fastest runners showed larger magnitudes of velocity decreasing when compared to the slowest runners during their foot contact phase. These results seem uncertain because of the number of participants and different training backgrounds of participants. Only one sprinter participated in Payne et al.'s study; five distance runners were in Bates's study. Morin, Edpuard, and Samozino (2011) stated that high accelerations in running and bouncing bipeds were achieved by increasing the amount of propulsive force and concomitantly decreasing the amount of braking force. For better performance foot contact time should be as short as possible with an optimal ratio of braking and propulsion phases (Coh, Peharec, & Bacic 2007). Thus, further study is needed to confirm whether fast sprinters can minimize velocity loss during initial foot contact phase. In addition, whether this velocity loss during initial foot contact is correlated to sprint performance during the maximal running velocity performance is still unknown.

2. **Using kinetic isometric mid-thigh pull variables to predict D-I male sprinters' 60m performance**

Isometric mid-thigh pull has been used to test strength variables among athletes (Khamoui, Brown, Nguyen, & Uribe, 2011; Stone et al. 2004). The relationship of the isometric mid-thigh pull with short distance sprint performance also has been investigated in previous studies (West et al. 2011). However, due to testing procedures and participants' background differences in previous studies, a correlation between isometric pull mid-thigh data and sprinters' 60 m sprint performance remains unclear. Strength and ability to produce greater force during a short period of time are important factors for dynamic movements. The current study was to determine if using isometric mid-thigh pull could also be a reliable and valid measurement to predict college level sprinters' 60 m sprint variables.

3. **Influence of whole and lower body angular momentum cancellation during terminal swing**

Based on Newtonian mechanics, a body system must conserve its angular momentum during the flight phase. Once the foot contacts the ground, the whole body angular momentum cannot be conserved due to braking force from the ground. However, robotics experiments have indicated the opposite direction of support and swing legs' movements could better preserve whole body angular momentum and achieve better running performance if the timing was right

(Raibert, 1986). Hopper (1969) also indicated that timing of movement could influence force generation during the foot contact phase.

Currently there is no previous study focused on body segments interactions during the actual sprinting event. However, based on previous studies (Mann & Herman1985; Vardaxis, 1988) that either analyzed the support leg or the swing leg motions, fast sprinters showed faster support leg retraction and forward leg swing movement before foot contact with the ground than slow sprinters. Momenta that are generated by the support and swing legs could balance and counteract each other (Raibert, 1986). This might explain why fast sprinters can preserve angular momentum during the foot contact phase, which may improve running efficiency and performance. Thus, to better understand these it is important to analyze the interactions of body segments related to the sprint performance between fast and slow sprinters.

Statement of Purpose

1. To identify the relationship of acceleration of center of mass (CoM) during subsequent foot contact phase. In addition, if this magnitude of acceleration is related to sprint performance.
    - Changing of acceleration of CoM during foot contact phase.
    - Changing of velocity CoM during foot contact phase.
2. To determine if isometric mid-thigh pull could be an indicator of sprinters' performance.
    - Kinetic (instantaneous forces @ 50, 90, 150, and 200 milliseconds (ms), rate of force development, impulse @ 50, 90, 150, and 200 ms and peak force) of mid-thigh isometric pull to 60 m sprint performance.
3. To determine if fast sprinters could better preserve angular momentum during the foot contact phase.
    - Fourteen segments human model angular momentum
    - Whole body angular momentum around center of mass
    - Maximal running velocity
    - Angular momentum cancellation coefficients

Research Hypotheses

H1. Less horizontal CoM velocity loss during the foot contact phase positively correlate with maximal velocity running performance.

H2. Kinetic characteristics from isometric mid-thigh pull variables can positively relate to sprint performance.

H3. Fast sprinters show a higher value of angular momentum cancellation coefficient during the terminal swing phase.

Importance of Study

This study identified the relationship of acceleration of CoM during the foot contact phase and maximal running velocity performance. In addition, the current study determined the role of horizontal CoM velocity loss during the foot contact phase for maximal running velocity performance.

Next, this study explored and determined the importance and validity of isometric mid-thigh pull kinetic variables for sprint performance. Kinetic variables (force production within 100 milliseconds) from isometric mid-thigh pull may play an important role to predict sprint performance. Therefore, coaches and sport scientists can better monitor training effects for sprinters' performance.

Last, the interaction of lower body (support leg and swing leg) during terminal swing phase may assist to force production during subsequent foot contact phase. Thus, the interaction of lower body during terminal swing phase (prior to foot contact phase) may correlate to maximal running velocity.

Assumptions

It is assumed that all athletes tested from East Tennessee State University represent all track and field athletes at Division I NCAA institutions. It is also assumed that all participants are not affected by injury as self-reported. The current study also assumed that all participants performed maximal effort sprint and isometric pulls.

Delimitation

This study consisted of volunteers from the athletic population participating in the Sports Performance Enhancement Consortium (SPEC) program at the Center of Excellence for Sport Science and Coach Education (CESSCE) at East Tennessee State University. Participants were limited to those who are familiar with the SPEC testing protocol. However, not all of them had experience with isometric mid-thigh pulls. For this reason familiarization of the test protocol seems important for volunteers in the present investigation. Volunteers were also required to be healthy and free of any significant injury or surgical repair within the past year.

Definition of Terms

Braking force—horizontal ground reaction force acting against the horizontal running direction of the sprinter.

Propulsive force—horizontal ground reaction force acting with horizontal running direction of the sprinter.

Contact phase—support leg that first contact with ground until it leaves off ground.

Flight phase—no foot in contact with ground.

CoM—center of whole body mass

CoM_i—center of mass ith segment

I_{CoMi}—the moment of inertia tensor of the ith segment.

—angular velocity vector of the segment.

r_i—relative position of ith segment CoM_i to the whole-body CoM position.

v_i—relative velocity of the ith segment CoM_i to the whole-body CoM velocity.

P_i—linear momentum of the ith segment.

m_i—mass of the ith segment

$_{i,local}$—ith segment local angular momentum.

$_{i,transfer}$—ith segment transfer angular momentum;

$_{whole}$—whole body angular momentum.

—adjusted whole body angular momentum.

CHAPTER 2

COMPREHENSIVE REVIEW OF LITERATURE

History of Human Movement Analysis

Scientists' interest in understanding human movement can be traced back to antiquity. French physiologist Etienne Jules Marey made great contributions to knowledge of the mechanics of the locomotor apparatus (Braune & Fischer 1987). Marey invented a new method of research, making practical use of chronophotography for the direct measurement of the process of movement. He was able to create projected images of motion and the passage of time. Marey's work played an important role in current scientific research in the field of movement study.

The first attempt to investigate the phases of movements was American photographer Eadweard Muybridge. He was the first to photograph a series of successive movement phases of a trotting horse. Later, locomotion image of humans was also published by Muybridge. Muybridge`s book consisted of sequential still photographs of men, women, and children performing many physical activities such as walking, running, and so on. Although there were no calculations involved, the techniques that Muybridge initiated became a foundation of future investigation (Latash & Zatsiorsky, 2001).

Comparisons in leg swing movements during locomotion among different levels of sprinters have been conducted since the 1970s. Actually, studies that focused on the movement of swing leg could trace back to the Webb brothers' study on walking. We are all deeply indebted to the Webb brothers for modern physiology; they led locomotion science in new directions (Latash & Zatsiorsky, 2001). Their work "The mechanics of human walking apparatus" that was published in 1894, led to the interest in analyzing gait and muscle function and for the work of other scientists in this area.

After the Webb brothers' work, Braune and Fisher, from 1895 to 1904, used analytical methods that involved design, construction of new equipment, and complicated mathematical calculations to quantify the rotatory movement the of leg with the following equation: $m*x^2*\alpha=D_m+D_s+D_e$. The equation consists with "m" representing mass; "x" is the radius of inertia with reference to the axis through the center of gravity, and "α" is angular acceleration. "D_m", "D_s", and "D_e" represent the torques exerted by muscles, gravity, and effective forces on the portion of the leg being examined. From the equation they knew how much torque had been generated by the muscles. They concluded gravity was not the only force acting on the lower leg during motion.

General Description of Sprint Biomechanics

From a biomechanical perspective sprinting like walking gait is a pattern of cyclic movement. It starts when one foot comes in contact with the ground and ends when the same foot comes into contact with the ground again. Each cycle has a phase of support from the time foot contacts the ground in the leading position until the same foot leaves the ground become trail position. Each cycle includes a phase of flight or forward recovery when the lower extremity does not bear weight but swings from a trail position to a leading position to prepare for the subsequent foot strike. Different from a walking gait, the stance phase in walking is longer than 50 % of the gait cycle. Walking has periods of double support—one foot at the beginning and other one at the end of stance phase. In sprinting the toe off occurs before 50 % of the gait cycle, so there is no period of both feet on the ground. Instead, both feet are in the air; one is beginning and other one is ending the swing phase.

Some researchers subdivided the foot contact and swing phases for a better comparison and analysis of sprint performance. From a kinematic perspective researchers (Novacheck, 1998; Slocum & James 1968) divided the foot contact phase into initial contact phase that begins as the foot first contacts with the ground; mid support (aka., stance reversal) that starts after a short period of absorption; CoM starts to be propelled to upward and forward during the stance phase; and the toe off phase is when the toe starts to rise and leave the ground.

After a series of tests running on a force platform, Payne et al. (1968) found a braking thrust early during the foot contact, followed by a propulsive thrust. The magnitude of braking force was different based on the different phases of running. At first step of the acceleration phase the braking force was small and almost nonexistent. Propulsive force played a bigger portion during the contact phase.

During the constant speed running phase, the subject in Payne et al's (1968) study ran with an average speed of 8.8 yard/s (8.05 m/s) race. After ignoring the air resistance, they found that the average of braking and propulsive forces was zero. Based on their findings, the authors proposed that the smaller magnitudes of the braking and propulsion forces, the more efficient the running. However, studies (Mann., 2011; Miller, Umberger, & Caldwell 2012) indicated that sprint performance related to the propulsive force that sprinters applied to the ground. The larger the force applied to the ground by sprinters, the faster they can run. Thus, the effects of deceleration during braking phase and its related variables for sprint performance need to be investigated. In addition, whether the ratio between the braking and propulsion phases has effects on sprint performance is still unknown and also deserves further study.

Different Phases of Sprinting

Pursuing a faster running speed is one of the most important matters for coaches and athletes in those sports that require speed, particularly in sprinters. Based on velocity time curve, sprint running is divided into acceleration, maximal velocity, and velocity maintenance phases. However, some researchers and coaches consider the block start as one single phase. (Mero et al., 1992).

The block start refers to athletes striving to leave the block as quickly as possible and at the same time obtain the highest possible forward and vertical acceleration (Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers 2013). The acceleration phase is characterized by a forward leaning position of the sprinters' body and speed development from powerful extension of the lower extremity joints and the trunk, gradually attaining an upright sprinting position to achieve maximum velocity phase. During the maximal velocity phase, the trunk stays upright and the time required to rotate the legs forward and backward relative to the hip joint will limit further acceleration from a kinematic perspective (Debaere et al., 2013). The velocity maintain phase is the remainder of the race. Sprinters need to maintain speed and postpone deceleration until reaching the finish line. The distance of each phase is different based on the gender and level of the sprinters.

Performance at these distinct running phases is directly related to the final results. Debaere et al. (2013) found that the length of the acceleration phase varied between 35 and 48 m for women. Men showed a longer distance, from 41 to 59 m. Coh, Peharec, and Bacic (2007) indicated that world level sprinters reached 8.15 m/sec at 10 m and reached their maximum velocity of 11.67 m/sec between 50 m to 60 m. For example, Usain Bolt reached 9.05 m/sec at

10 m and reached his maximum velocity of 12.2 m/sec between 50 m and 60 m during 2008 Beijing Olympic Game.

The performance in each of these running phases depends on specific technical skills that relate to the particular biomechanical and physiological demands of each phase. Thus, physical and technical training of sprinting athletes should focus on the requirements of each of these phases of sprint performance (Debaere et al., 2013).

Block Start

For a better analysis of 100 m sprint performance, some researchers conducted kinetic and kinematic studies of the block start, acceleration, and maximum velocity phases of 100 m sprint. Fortier, Basset, Mbourou, Faverial, and Teasdale (2005) indicated that the sprint start is a complex motor task that requires athletes to exert large forces in the horizontal direction in a short time period. During the study (Fortier et al.,2005) stated that the delay between the end of the rear block and front block force offset generated from rear and front legs was the main determinant of the start block performance between elite and subelite sprinters. The delay between the end of rear block and front block forces offset directly affected the total block time and that is an important indicator to assess block start performance. Both the elite and subelite sprinters can generate higher front block peak force than rear block peak force, but the elite sprinters can generate higher rear peak force than subelite sprinters. The authors concluded that better sprinters have developed specific motor patterns adapted to the sprint start task and developed a greater rate of force development than their counterparts (Fortier et al., 2005). Bezodis (2009) also confirmed that a good sprinter produced higher than average hip extension velocities across the propulsion phase, especially at the rear hip. In contrast, slower sprinters showed larger and faster extension at the distal joints (faster extension of knee and ankles joints during the start from the block), which are not considered as very efficient movements.

Jacobs and Van Ingen Schenau (1992) indicated that sprinters showed proximal to distal sequence during sprint push off performance and the performance related to the transfer of the segments' rotation motion to horizontal translational velocity; Bezodis (2008) supported and indicated that faster sprinters appeared to create more rapid rotations of the thigh segment over a greater range of motion without any associated increase in stance time during the start phase.

Acceleration Phase and Body Position

Kugler and Janshen (2010) found that body position determines propulsive horizontal force during the acceleration phase of running. They found faster sprinters demonstrated larger propulsive ground reaction force related to overall ground reaction force than their counterparts. During most of the stance phase of the acceleration the faster sprinters showed similar propulsive force to slower sprinters; however, faster sprinters demonstrated greater angles between CoM related to the vertical axis at the latter part of the stance phase than slower sprinters. To achieve this the faster sprinters either had greater forward oriented angles of attack or longer foot contact times. The latter are shown by greater takeoff angles because the CoM is further forward during the ground contact phase.

Maximal Velocity Phases

After the acceleration phase sprinters gradually attain an upright position and achieve their maximum velocity. One of the reasons is because of the proportion of the horizontal force is limited by the upright position. The other reason is that skeletal muscles cannot generate bigger forces at faster contraction rates.

According to Miller et al. (2012) sprinting performance is sensitive to the force-velocity relationship. Faster sprinters' skeletal muscles can contract explosively and generate more force at certain speeds or can generate more force at faster speeds. It is not surprising that elite sprinters have higher speed, especially at the maximum velocity and the velocity maintenance phases.

Velocity Maintenance Phase

Once sprinters achieve maximum velocity, their goal is to maintain the speed. During the maximal velocity and velocity maintenance phases of sprinting the body achieves an upright position and the body is in a mechanical situation in gravitational constraints. Elite sprinters have the ability to maintain the maximum velocity, which is a critical factor for the 100 m sprint performance.

During the Tokyo track championship in 1991, the top five of the eight finalists of the 100 m sprint showed dramatic velocity during the maximum speed phase (Table 2.1). In addition, they did not show significant decrease of velocity compared to the rest of the sprinters, and the top five finalists showed a second peak maximum velocity phase at the end of the 100 m race (see Table 2.1). This second peak velocity phase indicated that elite sprinters have excellent anaerobic energy systems and neuromuscular systems. In addition, their sprint techniques also play an important role to let them maintain high-speed performance. Thus, it is necessary to make further study sprinting from physiological and biomechanical standpoints.

Table 2.1.
10 m Interval Sprint Performance from 100 m Race. Modified from Ae et al., (1992)

Name	Time parameters / average speed	10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m	90 m	100 m
Lewis	Elapsed (s)	1.88	2.96	3.88	4.77	5.61	6.46	7.30	8.13	9.00	9.86
USA	Interval (s)	1.88	1.08	0.92	0.89	0.84	0.85	0.84	0.83	0.87	0.86
	Average speed (m/s)	5.31	9.26	10.87	11.24	11.90	11.76	11.90	12.05	11.49	11.63
Burrell	Elapsed (s)	1.83	2.89	3.80	4.68	5.55	6.41	7.28	8.12	9.01	9.88
USA	Interval (s)	1.83	1.06	0.91	0.88	0.87	0.86	0.87	0.84	0.89	0.87
	Average speed (m/s)	5.46	9.43	10.99	11.36	11.49	11.63	11.49	11.90	11.24	11.49
Mitchell	Elapsed (s)	1.80	2.87	3.80	4.68	5.55	6.42	7.28	8.14	9.02	9.91
USA	Interval (s)	1.80	1.07	0.93	0.88	0.87	0.87	0.86	0.86	0.88	0.89
	Average Speed (m/s)	5.56	9.35	10.75	11.36	11.49	11.49	11.63	11.63	11.36	11.24
Christie	Elapsed (s)	1.85	2.91	3.83	4.72	5.57	6.43	7.29	8.14	9.04	9.92
GBR	Interval (s)	1.85	1.06	0.92	0.89	0.85	0.86	0.86	0.85	0.90	0.88
	Average Speed (m/s)	5.41	9.43	10.87	11.24	11.76	11.63	11.63	11.76	11.11	11.36
Fredericks	Elapsed (s)	1.86	2.92	3.84	4.73	5.60	7.47	7.33	8.18	9.07	9.95
NAM	Interval (s)	1.86	1.06	0.92	0.89	0.87	0.87	0.86	0.85	0.89	0.88
	Average Speed (m/s)	5.38	9.43	10.87	11.24	11.49	11.49	11.63	11.76	11.24	11.36
Stewart	Elapsed (s)	1.81	2.88	3.79	4.68	5.54	6.41	7.29	8.16	9.06	9.96
JAM	Interval (s)	1.81	1.07	0.91	0.89	0.86	0.87	0.88	0.87	0.90	0.90
	Average	5.52	9.35	10.99	11.24	11.63	11.49	11.36	11.49	11.11	11.11

Table 2.1 (Continued)

	speed (m/s)										
Da Silva	Elapsed (s)	1.91	2.97	3.90	4.79	5.67	6.56	7.45	8.32	9.22	10.12
BRA	Interval (s)	1.91	1.06	0.93	0.89	0.88	0.89	0.89	0.87	0.90	0.90
	Average Speed (m/s)	5.24	9.43	10.75	11.24	11.36	11.24	11.24	11.49	11.11	11.11
Surin	Elapsed (s)	1.88	2.95	3.87	4.77	5.66	6.56	7.44	8.31	9.22	10.14
CAN	Interval (s)	1.88	1.07	0.92	0.90	0.89	0.90	0.88	0.87	0.91	0.92
	Average Speed (m/s)	5.31	8.20	10.87	11.11	11.24	11.11	11.36	11.49	10.99	10.87

Stride Length and Stride Frequency

As discussed in the general description of sprint biomechanics, two components of sprinting that determine the rate of body movement over the ground are stride length and stride frequency. Stride length and stride frequency are the most important factors for sprinters, coaches, and sports scientists according to Babic, Coha, and Dizdar (2011). The ratio between stride length and stride frequency depends on an individual's anthropometry, strength level, and running technique. Sprint velocity is produced by an optimal ratio between stride length and frequency. Hunter, Marshall, and McNair (2005) indicated that in order to increase running velocity, stride length, stride frequency, or both must increase. Hunter et al. (2005) stated that stride length was related to sprint velocity, and that stride frequency was not. However, for individuals, the sprinters tended to produce their fastest trial with a higher stride frequency, not a longer stride length. After testing a sprinter running on a treadmill at five different speed conditions (6.71 m/s, 7.60 m/s, 8.49 m/s, 8.94 m/s, and 9.49 m/s), Chapman and Caldwell (1983) indicated that due to successful completion of leg recovery delay the reduction of leg energy prior to the foot landing; the delay reduction of leg energy prior to the foot landing let the fast sprinters spend more time in the flight phase and modified the relationship between stride length and stride frequency at high speeds. The authors believed that completion of leg recovery is a factor to limit maximal speed.

Mero and Komi (1986) found their subjects' stride length and stride frequency increased as running speed increased but not in a linear fashion. Stride length leveled off at maximal speed, while stride frequency still increased at the supramaximal speed. The authors indicated the sprinters' backgrounds also play an important role for the interaction between stride length and stride frequency (Mero & Komi, 1986). They concluded that elite sprinters can produce longer stride lengths and relatively faster stride frequencies when compared to subelite sprinters.

Hunter, Marshall, and McNair (2004) divided stride length and stride rate into subcomponents such as stance time (foot contact time), stance distance, flight distance, and flight time. In general no matter what phase sprinters execute, sprinting is a cyclic movement that involves contact and swing phase, one phase influencing the succeeding phase. Mann (2011) stated that over-extension of the support leg would influence its forward swing movement, then it would influence landing performance when it lands again. So, the mechanics of performances at those two phases deserve to be studied in a more detailed manner.

Determinants of Foot Contact and Flight Phases for Sprint Performance

As illustrated earlier, during the sprint the foot contact phase is characterized by a decelerating phase followed by a propulsion phase (Morin et al., 2011; Payne et al., 1968). From a kinetic perspective the foot contact phase is divided into braking and propulsive phases. As the sprinter leaves the block, velocity increases and accompanied by the erection of body position, braking force also increases. According to Bezodis (2009) the mean peak braking force magnitude was also found to increase over the first four steps (215, 348, 421, and 672 N, respectively). As the sprinter achieves maximal velocity, due to the upper body being totally erect, there is no further horizontal force increase. For better performance foot contact time is supposed to be as short as possible with an optimal ratio between the braking and propulsion phases (Coh et al., 2007). Actually, the interest of finding effects of braking phase during the contact phase in sprint performance can be traced to early researchers.

Previous studies also analyzed and determined important variables related to sprint performance. According to Hunter et al. (2004) flight time was decided by the vertical force produced by sprinters during foot contact phase; Weyand, Sternlight, Bellizzi, and Wright (2000) stated no difference in flight time between fast and slow sprinters was observed. However, other studies found differences (Dilman 1970; Mann & Herman 1985; Vardaxis 1988) in swing leg movement between fast and slow sprinters during flight phase. Details of previous research are discussed as follows.

Kinematics

By analyzing the kinetic energy of the lower extremity movement of sprinters physiologist Fenn (1930) found that work done by muscle contraction against viscosity is a fraction of energy expended; during the study Fenn (1930) found some biomechanical characteristics of his participants that included stride rate, stride length, horizontal velocity of the backward leg swing related to CoM before the foot contacting ground, the angle of the support leg touch down, and so on. He stated that his fastest subject showed faster leg back swing velocity relative to CoM velocity before the foot contact on the ground. Fenn (1930) also found that the faster subjects showed a closer distance between the touch-down foot and CoM. Moreover, the touch-down angle is also steeper for faster subjects than slower ones. Fenn stated that might relate to better energy management. However, the study did not go further to confirm the relationship of those kinematics of the lower extremities to sprint performance.

Running patterns between different levels of sprinters and ages were studied by many researchers (Clause, 1959; Dittmer, 1962; Teeple, 1968). Studies that analyzed running and sprinting from an age development perspective provided a better understanding of changes in movement pattern related to increase running velocity. After a 7-month observation different ages of preschool boys' running performance by continuous photographs, Clouse (1959) indicated that estimated CoM of body height increased with the skill of the subjects and the age level. Average horizontal velocity increased from 1.38 m/s to 4.15 m/s, and 2.11 m/s to 4.37 m/s, respectively from the youngest to the oldest boys. Stride length and relative stride length also increased during the observation period (see Table 2.2). Those phenomena indicated strength level and running technique improved, even the length of their legs also increased. The relative stride length increased at all ages, except the youngest subject.

Table 2.2.
Comparison of Sprint Kinematic Variables Between Boys in Different Ages. Modified from Clouse (1959)

Subject	Testing session	Stride length (cm)	Leg length (cm)	Relative stride length
Willian 1.5 yrs.	1st	25.6	30.2	0.85
	Last	34.5	35.7	0.97
David 2.5 yrs.	1st	38.4	37.3	1.03
	Last	61.1	40.2	1.52
John 3.5 yrs.	1st	55	40.4	1.36
	Last	77.3	43.4	1.78
Larry 4 yrs.	1st	68	42.9	1.58
	Last	77.9	44	1.73
Malcolm 5 yrs.	1st	68.9	45.3	1.54
	Last	98.2	49.4	2

However, Clause (1959) indicated more propulsive movements were acquired with age as skill increased. The angular velocity of ankle, knee, and hip extension increased at takeoff. The proportionately of the propulsive movement increased as the running performance improved. In addition, the author stated that the movements and angular velocity of the recovery leg increased, especially the forward movement of the thigh. Clause indicated that recovering the thigh made a contribution to the greater horizontal running velocity. But, unfortunately, the author did not go further to confirm the assumption.

Dittmer (1962) stated that a runner exerting maximum effort could greatly increase speed by swinging the recovering limb forward at a faster rate. A faster rotating rate could increase stride rate, subsequently increase running velocity if stride length was maintained. After observing girls at different ages, Dittmer (1962) found a pattern of running development and factors that distinguish good and poor running performance. During the observation period better runners had the greater ankle and knee flexion of the support leg at the foot contact phase (Table 2.3), greater velocity of the support leg at the foot contact and take off phases, greater hip flexion (Table 2.4), and the swing leg velocity at the foot contact phase resulting in a longer reach; The distance between the contact foot and CoM was closer at horizontal plane than in poor runners. Dittmer indicated that as time of the foot contact phase decreased, the proportion of propulsion increased (the author was depending on the knee flexion to define braking and propulsion phases). Similarly, due to equipment limits some errors may have been involved in calculations because the authors used a clock time captured by a picture to calculate kinematic related variables. Further confirmation needs to focus on the proportion of the propulsion phase and its correlation with sprint performance.

Table 2.3.
Knee Flexion of Support Leg at the Instant of Contact

Performer	Angle degrees/ Testing time			
	1955	1956	1957	1959
S1 Better	138	142	141	N.A
S2 Better	160	148	146	145
S3 Poor	159	150	152	147
S4 Poor	153	155	154	145

Table 2.4.
Hip Flexion of Swing Leg at Takeoff (Better Runners Had More Flexion)

Performer	Angle degrees/ Testing time			
	1955	1956	1957	1959
S1 Better	135	109	102	N.A
S2 Better	106	95	92	105
S3 Poor	110	120	110	123
S4 Poor	129	127	115	122

Teeple (1968) tested 28 college female students' sprint performance. The foot contact time (r =-0.73, p =0.01) and stride length (r =0.46, p = 0.05) were positively correlated with maximum speed only. Statistical differences were seen between fast and slow runners, but no statistical significance correlation of swing leg movements with maximum speed was found. The authors indicated that limitation of the study are because of performance among the subjects being homogenous. More cross-sectional subjects such as elite, subelite, and different sexes might provide better understanding about determinant variables related to sprint performance.

Using calculations from Braune and Fisher, Dillman (1970) did further study about the general pattern of muscular torques of the leg during the recovery phase of sprint running. He found among the six sprinters that all sprinters had the same general pattern (they started from positive—muscle concentric contraction and change to negative—muscle eccentric contraction), but differences existed in the magnitudes, rates, and timing of the transition between the two phases when comparing the fastest subject to the others. However, how those differences affected the subsequent foot contact phase remain unknown.

For better analysis differences during the foot contact phase among runners, Bates et al. (1979) studied five female runners and their 400 m performance ranges from 51.8 to 55.8 sec. As compared to previous studies, the authors found the fastest runner showed the greatest CoM decreased in velocity (0.68 m/s) during the foot contact phase from 8.33 m/s to 7.65 m/s, while the two slowest runners showed more constant value, as velocity decreased 0.14 m/s, from 7.17 m/s to 7.03 m/s, and 0.39 m/s from 7.03 m/s to 6.64 m/s respectively. Due to the number of participants in the study, further comparison could not be made. Thus, the role of CoM velocity decrease during the foot contact phase for sprint performance is still unclear.

Mann and Herman (1985) recorded a 200 m race in the Olympic Games to determine the important kinematic variables for sprint performance. After comparing the first three medalists and the eighth-place finisher, the authors concluded the determinant parameters are influential sprint performance: 1) less leg extension at the takeoff phase, 2) thigh rotation velocity during the foot contact phase, 3) higher backward leg swing velocity related to CoM at the touch down, and 4) closer distance between touch down foot and CoM. In the study by Mann et al. (1985), the arm and shoulder movements were not correlated with sprint performance, which contradicts with many coaches' instructions. Similarly, Ae et al. (1992) compared college sprinters to Lewis and Burrell who won first and second place in the 1991 Tokyo World Championship. The two elite sprinters had higher backward leg swing velocity (650 deg/s) before the foot contact with the ground compared to college level sprinters (400 to 500 deg/s). Thus, Ae et al. stated that faster sprinters could minimize braking force during the initial foot contact phase. Similarly, these studies did not include further calculation of those variables and how these differences related to maximal running performance. Vardaxis (1988) analyzed mechanical performance of the swing legs of 100 m sprinters and further divided the swing phase into three subphases: 1) lift-off, 2) swing through, and 3) landing phase from the 2-D sagittal plane kinematics characteristics. When comparing between advanced and intermediate level sprinters, he concluded that the advanced and intermediate sprinters shared a similar shape and number of power phases based on their movements (Figure 2.1).

However, regarding the value of power and angular velocities, advanced sprinters produced earlier and higher peak values during stride (swing phase) than intermediate sprinters did (Table 2.5). In addition, although the timing of lift-off and swing- through during the swing phases was not correlated with horizontal velocities, the author stated that vigorous forward swing of the recovery leg increases the ground reaction force of the support leg and enhances the forward thrust. The thigh terminates its forward swing at approximately the same time as the take-off of the opposite leg thus reversing its direction. Vardaxis found the magnitude of power flow differences during the swing phase between faster and slower sprinters. However, how these differences of the swing leg performance between sprinters related to sprint performance are still not clear.

Figure 2.1. Swing leg movement at concentric and eccentric phase. (Modified from Vardaxis1988)

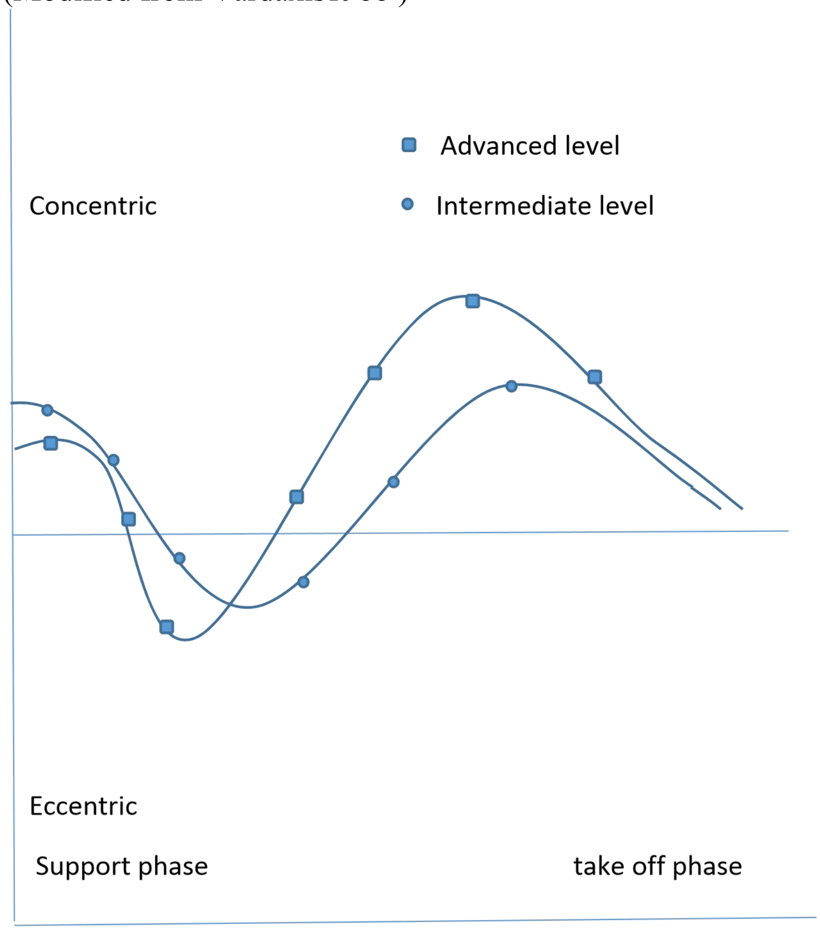

Table 2.5.
Comparison of Swing Leg Variables Between Advanced And Intermediate Level Sprinters. (Vardaxis 1988)

Variables	advanced sprinters (average)	Intermediate sprinters (average)	p<
Peak hip power	1638.9	1138.9	0.001
Time to peak	38.97%	41.67%	0.031
Peak relative flexion velocity	16.3	15.1	0.115
Peak relative extension	10.3	7.9	0.001
Peak knee power	1092.9	774.9	0.001
Time to peak	43.76%	43.21%	0.699
Peak flexion velocity	21.3	18.7	0.001
Peak extension velocity	20.7	17.4	0.001

In a literature review Mero et al. (1992) concluded that top sprinters in the world showed highly positive correlations between stride length and the 100 m performance (r = 0.70). Males have s longer stride length than females. The vertical displacement of CoM is also different among sprinters, 0.047 m for “good” (9.86 m/s), 0.050 m for “average”, and 0.062 m for “poor” (9.24 m/s) male sprinters, respectively. The data indicated that CoM vertical displacement is smaller for better sprinters. Decreases of horizontal velocity at the initial foot contact phase is also different based on the different sprinters. The authors indicated that decreases of 0.39 m/s for “good” sprinters, 0.43 m/s for “average” sprinters and 0.53 m/s for poor sprinters. Although the threshold to separate “good” and “poor” was not established, the authors indicated that the primary reason for the decrease in running velocity is the horizontal distance between the first contact point and the CoM the at touch-down. However, “the magnitude of the braking force is thought to be a function of the foot speed relative to the ground at foot strike and the distance between the foot and the total body CoM at foot contact, although the relationships between these variables have never been fully tested" (Putnam & Kozey, 1987, p 31) .

Miller et al. (2012) also indicated during his simulation model study, speed is limited by the rate at which the hip flexors can generate enough energy in the lower limb to rapidly move it forward and complete the swing phase, knee flexor (hamstrings and gastrocnemius) in late swing serves to arrest this motion in preparation for foot contact to decrease braking force. In addition, Miller et al. demonstrated the magnitude of the force that a muscle can generate at a fast contraction rate is also a determinant for sprint performance. Thus, fast sprinters can swing the leg faster during the swing phase and rotate faster and generate greater forces on the ground during the maximal velocity phase.

Compared to the sagittal plane, there are limited studies reporting gait biomechanics in the transverse plane. Hinrich, Cavanagh, and Williams (1987) indicated that during running the CoM deviates less from side to side because the arms cover a relatively large excursion side to side. The authors stated that portion of crossover of forearm and hand in front of the body at the end of the forward swing coordinates with an opposite side-to-side motion of the rest of the body; the momenta produced from these movements tend to cancel out each other because of opposite movements' direction. This leads to a more constant horizontal movement. Moreover, this opposite side-to-side motion between the arm and lower body also seems to reduce energy expenditure during running.

From a clinical perspective, Novacheck (1998) stated it is difficult to understand joint rotation in this plane and it is hard to capture accurate kinematic information. However, there are two parts for concern. First, pelvic rotation internally in mid-swing phase, to lengthen the stride and rotation externally at the initial foot contact phase; this movement maximizes horizontal propulsion force and minimizes loss of speed. The other important motion is foot pronation and supination during the foot contact phase. During initial landing foot pronation occurs to absorb the impact and energy, and then foot supinates in the next to provide a stable lever for pushing off.

Kinetic

Mann and Sprague (1980) found that in order to minimize braking force, sprinters tend to pull the body forward and over the touchdown point during the initial touch down phase. There are two factors that showed high correlations with braking force at the touch down and support phase, one is the subjects' body weight ($r = 0.64$, $p = 0.05$) and the other is relation between high braking force and loss of horizontal velocity at the foot contact phase ($r = 0.71$, $p = 0.01$). The second factor seems a little contradictory with some other studies (Coh et al. 2007; Dimmter 1962; Payne et al. 1968; Slocum et al.1968). Moreover, Mero and Komi (1986) stated that braking force should be as small as possible to decrease the loss of velocity during the initial foot contact phase. In addition they found differences in velocity decrement during the foot contact phase between two groups of sprinters, 0.11 ± 0.15s and 0.34 ± 0.31s ($p < 0.05$), respectively for fast and slow sprinters. However, they did not specify the causes of differences in velocity decrement during the foot contact phase.

The differences in outcome from those studies are probably because of the subjects' backgrounds and definition of brake and propulsion phases between studies. For example, Dimmter (1962) used knee flexion to define brake and propulsion; Mero and Komi (1986, 1992) used vertical movement of CoM to calculate braking and propulsion phases, although they used a force platform. Based on the latest kinematics calculation (Cici, Michele, & Merni 2010), the methods used by Dimmter (1962) and Mero and Komi (1986) to define braking and propulsion phases are not the same (not occurred at the same time during foot contact time). Mann and Sprague (1980) defined the two phases by force plate. Moreover, Hunter et al. (2005) stated that braking force might have beneficial effects for sprinters such as storage of elastic energy for next the propulsion phase. The effects of a braking force for sprint performance still needs to be studied.

Hunter et al. (2005) analyzed 28 subjects' braking and propulsion phases during the acceleration phase. The subjects ran 16 m from a start line and passed the testing zone. The authors found that foot touch-down velocity, touch-down distance, and a large touch-down angle could decrease braking impulse. However, braking impulse only accounted for 7% of the variance of sprint performance based on their regression analysis. The study confirmed that faster sprinters produced greater relative propulsive impulses during the foot contact phase. Thus, it seems that only propulsive force plays a significant role in sprint performance. Bezodis (2009) used a forward dynamics model to predict the effects of toe velocity for first step performance from block start. He found that that velocity of the landing toe at touchdown influences propulsive force. Compared to slower landing toe velocity, the relative faster toe velocity at touch down followed by larger magnitude of propulsive force.

Morin et al. (2012) found that technical ability to produce high net positive horizontal force was a determinant factor for 100 m sprint performance. But the study did not include effects of braking force for participants in the study. Hunter et al. (2005) focused on the acceleration phase, and the propulsion phase plays more dominant role and body position is still not totally upright; so, whether a faster sprinter could minimize braking phase in the maximal velocity phase and maintain velocity during the rest of race is still unknown. In addition, Hunter et al. (2005) also indicated an indirect contribution of the swing limb to the propulsion phase.

Yu (1993) stated that in his triple jump study “during the support phase of triple jump, three of four limbs are in the swing phase. As these free limbs are accelerated during a support phase, they exert forces on the trunk. These forces are transmitted through the leg to the ground. These lead to a modification of ground reaction force exerted by the ground on the athletes` body. The ground reaction force and its moment, serve to modify the translation of rotation and rotation of athletes’ body during support phase”(p.1). Similarly, it has been thought for a long time that during the foot contact phases of sprinting the actions of the swing leg assist with maintain horizontal velocity; however, no study could confirm this.

Correlation of Sprint Performance with Kinetic Testing Measurement

According to Stone et al. (2004) strength is the ability to generate force. The greater the force can produce, the better performance would be, as has been shown in many sports events such as cycling, weightlifting, throwing events, and so on (Haff et al. 1997; Stone et al. 2003; Stone et al. 2005). Conversely, the role of strength can’t reached an agreement based on the results of previous studies (Baker & Nance 1999; McGuigan & Winchester 2008; West et al. 2011). That might be due to testing methodologies and participants’ backgrounds differences that exist in previous studies. However, based on the reviews of previous studies, more studies found correlation between maximal strength variables and sprint performance (Table 2.6). Limitations were only a few studies recruited sprinters as participants, and the distances measured were different. Thus, further study is needed to confirm the role of maximal strength variables for sprinters performance.

Table 2.6.

Studies Review On The Maximal Strength Variables Related To Sprint Performance.

Authors	**Testing**	**Participants**	**Sprint variables**	**Results**
Baker et al. (1999)	3RM squat, 3RM hang power clean (PC)	20, pro rugby players	10, 40 m time	**10 m 40 m 3RM** NS NS **3RM rel** NS -0.66* **3RM PC** NS NS **3RM PC rel** -0.56* -0.72*
Bissas et al. (2008)	Both leg extensors isometric contraction	9 trained males	35 m speed	**Maximal running velocity Maximal strength** NS
Comfort et al. (2013)	3 RM squat	34, around 17 yrs male soccer	5, 20 m time	**5 m 20 m Absolute** -0.596* -0.645* **Relative** -0.519** -0.672*
Cunha et al. (2007)	Isometric leg press	72, athletes and non-athletes	60 m time	**60 m Leg press** -0.716**
Gissis et al. (2006)	Both leg extensors isometric contraction	54; 18 elite, 18 sub-elite, 18 recreational young soccer players	10 m time	PF, PF rel, F@100 ms, RFD, St 10 m could distinguish elite from sub-elite and recreational, however, NS between sub-elite and recreational.
Harris et al. (2008)	1 RM squat machine	30, 17 rugby training squad; 13 national rugby	10, 30/ 40 m times	**10 m 30/40 m BM 1RM** 0.2 -0.14 0.323 **1RM rel** -0.1 -0.33 -0.39
Hori et al. (2008)	1RM front squat, 1RM hang power clean	29 Australia football players	10 , 20 m time	**20 m 1RM FS** -0.60* **1RM FS rel** -0.51* **1RM HPC** -0.58* **1RM HPC rel** -0.57*
Knorr (2013)	1RM squat,	13 active males	5, 10 and 40 yard time	**5 yard 10 yard 40 yard 1RM** NS NS NS **1RM rel** NS NS NS
Lockie et al. (2011)	3 RM squat	20 healthy men	5, 10 m speed	**5m 5-10m 10 m 3RM** 0.43* 0.60* 0.47* **3Rm rel** 0.50* 0.66* 0.56*
Meckel et al.(1995)	Half squat	30; 20 female sprinters, 10 non-athletes	100 m time	Leg strength is one of most efficient variables to predict sprint time.
Mero et al. (1981)	Isometric knee extensor	25 male sprinters	Fly 30 m speed	**Maximal speed Force** 0.62***
Perkins, C.A. (1995)	1RM leg press	15, track and field	55 m time	**55 M 1RM** -0.524* **1RM rel** NS

Another important strength variable is the rate of force development (RFD). RFD is the indicator of person's ability to produce explosive force during a short period of time. Based on the previous study (Tillin et al. 2013), the ability to produce force within 100 ms was one of most important factor for sports because most of the movement occurred within 100 ms. However, there is a paucity of studies to confirm this especially with sprinters' performance. Therefore, it is necessary to investigate and confirm whether RFD is correlated with sprinters performance.

Isometric mid-thigh pull strength testing is one of the strength variables measurements and is used by many sports scientists and coaches. Based on the previous studies (Stone et al. 2003; Stone et al. 2004) that IMTP highly correlate with maximal strength variable. Conversely, previous studies using IMTP to predict dynamic movements were not consistent. Recently it was shown that force generation within 100ms negative correlated with 10 m acceleration performance in rugby players (West et al., 2010). Until now it was only study that showed correlation of IMTP performance with short acceleration performance. Thus, based on those previous studies, more questions need to be answered, for example, whether IMTP is also a valid and effective measurement to predict dynamic movement such as sprint event is still unclear.

There is a paucity of studies on the correlation between mid-thigh pull testing and college level track athletes' sprint performances (West et al., 2010). Peak force and rate of force development in the mid-thigh isometric pull and vertical jumps performances have been shown to be effective methods to test sprint performance in field players (Requena et al. 2009; West et al. 2011). However, whether this could assist coaches in assessing and monitoring college-level sprinters is still unknown.

Summary of Literature Review

Considering the findings from previous studies (Ae et al. 1992; Chapman & Caldwell, 1983; Dilman 1970; Mann et al. 1985; Vardaxis 1988) either focusing on support leg or swing leg performance between fast and slow sprinters; before the foot contact with the ground, faster sprinters shared one thing in common; they had a faster rate of support leg swing backward and a faster rate of swing leg moving forward. These two leg movements could assist faster sprinters in conserving full angular momentum during the subsequent foot contact phase, then improving landing efficiency. However, there is a paucity research focusing on this area to confirm this concept.

CHAPTER 3

Title: Kinematic Analysis Magnitude of Acceleration for Braking and Propulsion Phases During Foot Contact Phase at Maximal Speed Sprinting

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Abstract

Sprinters' performances are heavily influenced during foot contact phase of kinetics and kinematics. From the kinematics perspective specifically on center of mass (CoM) acceleration at horizontal direction, CoM acceleration can be subdivided into anterior and posterior components (braking and propulsion phases) during foot contact phase.

It is important to investigate those phases to understand how it relates to sprint performance. Thus the purpose of study is to determine the relationship between magnitude of acceleration for brake and propulsion during foot contact phase to maximal speed sprint performance.

Twelve division I level male sprinters participated in the current study. After dynamic warm up, the sprinters had run 2 trails of 100% effort of 60 meters sprint. Six cameras (Vicon Nexus) were used to capture full body kinematic data between 50 and 57 meters interval. The sprint times between 50 and 57 meters were measured by an electronic timing gate system (Brower Timing, Draper, UT, USA).

The magnitude of acceleration for braking and propulsion phases during foot contact phase showed statistic significant correlation to each other (r=0.96, p=0.000). However, the magnitude of acceleration for braking and propulsion phases during foot contact phase did not show correlation to 50-57 meters interval performance.

Conclusion: current study partially confirmed previous assumptions that "to achieve better sprint performance, sprinters should have short foot contact time with short braking and propulsion phases". However, the current study also found that some fast sprinters can also generate greater positive acceleration during propulsion phase to compensate larger negative acceleration during pervious braking phase.

Introduction

Sprinters' performances are heavily influenced during the foot contact phase of kinetics and kinematics. From kinetic perspective, foot contact phase can be further divided into braking and propulsive phases. Similarly, from the kinematics perspective specifically on center of mass (CoM) acceleration at horizontal direction, CoM acceleration can be subdivided into anterior and posterior components (braking and propulsion phases) during foot contact phase (Cicacci, et al., 2010). Previous studies (Payne, et al., 1969; Coh, Dolemec & Jost 1999) proposed that braking force should be minimized and propulsive forces maximized in order to improve sprint performance. Bates, et al. (1979) and Coh, et al., (1999) also stated that there should be an optimal ratio of braking and propulsion phases in the foot contact phase, to decrease horizontal velocity loss during the braking phases. However, differences among those previous studies may exist due to participants' background and testing. How those variables correlate to sprint performance still unknown. It is important to investigate those variables to understand how they relate to sprint performance. Thus the purpose of study was from a kinematic perspective to determine the relationship between magnitude of acceleration of CoM during braking and propulsion phases to maximal speed sprint performance.

Method

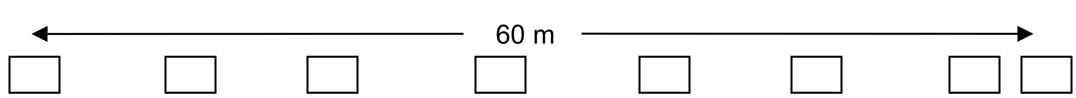
Twelve male (body mass: 75.28 ± 6.39 kg, body height: 1.79 ± 0.04 m, age: 19 to 21 years old) NCAA Division I sprinters (East Tennessee State University Track Team) participated in the study. Data was part of an ETSU athlete monitoring program. The participants read and signed University approved informed consent documents, prior to participation in this study.

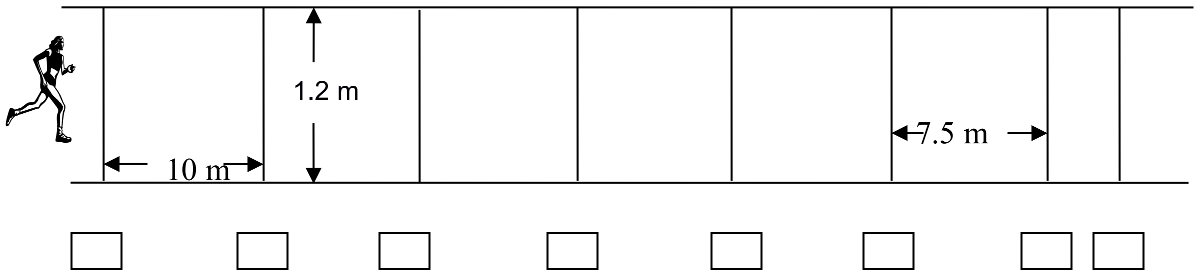
Sprint measurement

During the 60 m sprint testing session: two sprints from standing position were performed by each participant on an indoor 70 m long synthetic track with a lane width of 1.2 m. Before 60 m sprint testing, the participants had sufficient time to warm up, which consisted of dynamic stretching. Afterward, two maximal effort 60 m sprint trials were measured. To eliminate effects of fatigue, athletes were given a 10 minute rest period between trails. The sprint times were measured by an electronic timing gate system (Brower system, UT, US). Electronic timing gates were placed at 10 m intervals from the start line for 60 m. Thus average for each 10 m interval of sprint velocity was calculated from timing gates. 10 m intervals sprint speed (V 10, V 20, V 30, V 40, V 50 and V 60), sprint times of overall 60 m (St 60), were used for further analysis.

Motion Capture

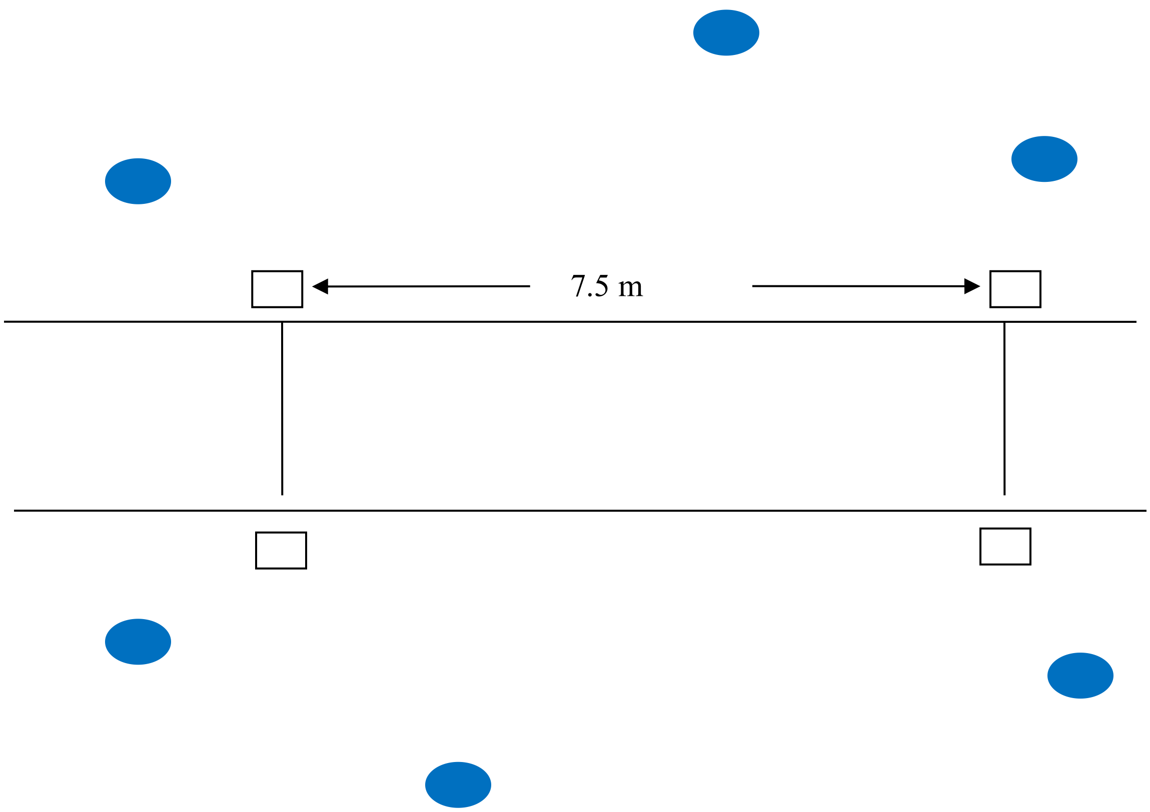
Kinematic data were collected using Vicon Nexus 1.8.5 video graphic and analog data acquisition system (Vicon, UK) with six cameras at a sampling rate of 240 frames/s. Reflective markers were placed bilaterally (shoulder, upper arm, elbow, forearm, wrists, finger, thigh, knee, shank, ankle, heel and toe) using a Vicon Full Plug-in-gait marker set. Diameters of reflective markers were 20 mm. The calibration volume was 7.5 m long, 1.2 m wide, and 1.9 m high. Running direction corresponded to X axis, Y was lateral axis and Z was vertical axis. Kinematic data were low pass filtered with a fourth Butterworth filter with cutoff frequencies of 15 Hz (Yu. 1989). The setup of cameras is shown in figure 1 and figure 2. An analyzable trial was a trial in which all kinematics data for two running step were recorded successfully by the system.





Represents timing gate

Figure 3.1. Sprint measurement



Represents camera

Figure 3.2. Kinematic data measurement from 50 m and 57.5 m.

Phase determination

According to Yu, Queen, Abbey, Liu, Moorman et al., (2008), the time of a foot strike was defined as the time represented by the first frame in which the vertical coordinate of the toe became a constant. The time of a toe off was defined as the time represented by the frame immediately after the last frame in which the vertical coordinate of the toe was constant. The time period between a foot strike and the subsequent toe off of the same foot was referred to as the foot contact phase. Definitions of CoM horizontal acceleration during braking and propulsion phases ($A_{negative}$ and $A_{positive}$) were from Cicacci, et al. (2010). Horizontal velocity changes of CoM (ΔV_h) during foot contact phase were calculated from differences of the smallest magnitude of velocity during foot contact phase and the initial takeoff phase.

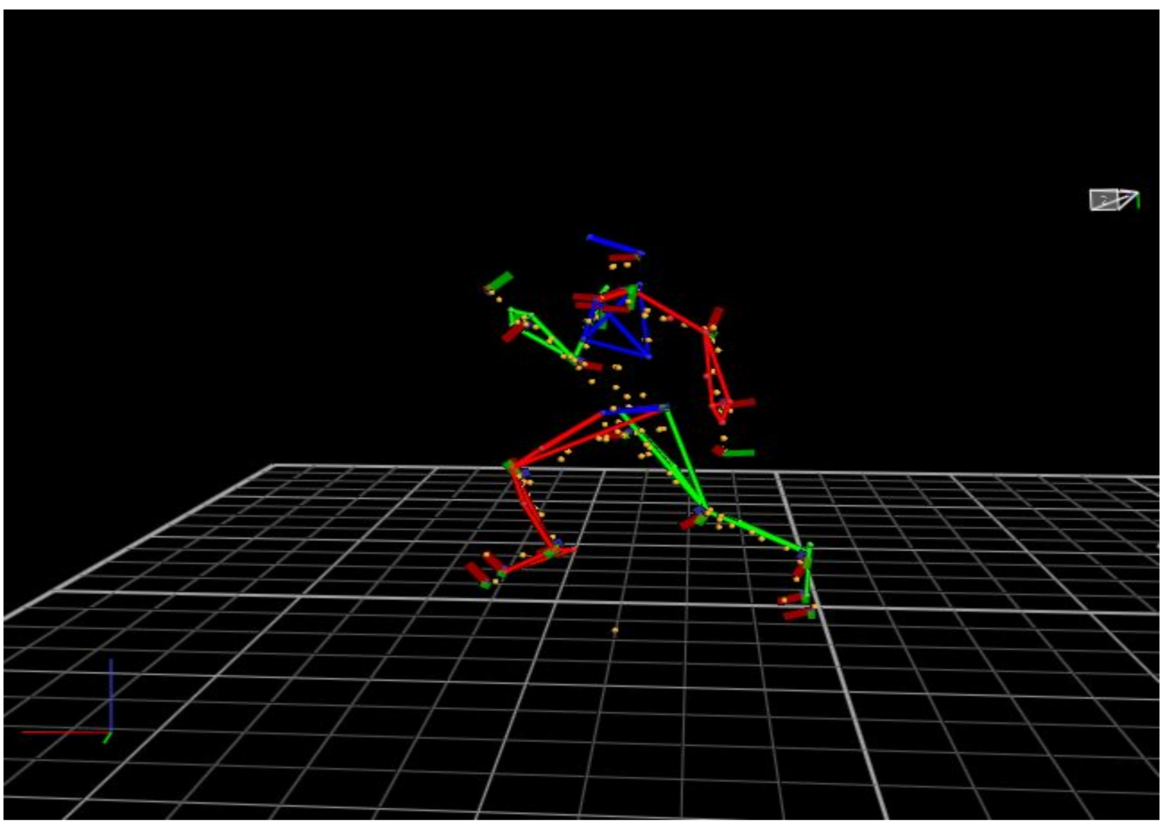


Figure 3.3.

Statistical analysis

T-test were used to test differences of kinematic variables between two steps, no statistical significance differences was found between them. Thus, average values of kinematics variables from two steps were used to further analysis. Sprint variables between two trails did not statistical significance neither. Correlation of kinematics and sprint variables, were performed using Pearson Correlation Coefficient test (SPSS 21). Statistical significance was set at $p \leq 0.05$.

Results

Descriptive statics were shown in table 1. Correlations of kinematics and sprint variables were shown in table 2. Negative and positive of CoM horizontal accelerations from braking and propulsion phases were highly correlated each other during foot contact phase; $\Delta \mathbf{V_h}$ was also showed statistical significance with negative and positive acceleration of CoM during foot contact phase. However, those three kinematic variables were not statistical significance correlated to sprint performance. Only little trends were observed in the correlation of V 50 and negative and positive of CoM horizontal acceleration.

Table 3.1.
Descriptive statistics.

Variables	Mean	±Std. Deviation
$A_{negative}$ (m/s^2)	-8.27	3.40
$A_{positive}$ (m/s^2)	10.29	6.10
St 57 (s)	0.81	0.04
St 60 (s)	7.15	0.37
V 10 (m/s)	6.11	0.75
V 20 (m/s)	8.48	0.45
V 30 (m/s)	9.13	0.36
V 40 (m/s)	9.44	0.51
V 50 (m/s)	9.38	0.43
V 60 (m/s)	9.33	0.46
ΔV_h (m/s)	0.61	0.15

Table 3.2.
Correlation matrix.

	$A_{negative}$	$A_{positive}$	St 60	V10	V 20	V 30	V 40	V 50	V 60	ΔV_h
$A_{negative}$	-									
$A_{positive}$	-.867**	-								
	0									
St 60	0.347	-0.414	-							
	0.27	0.181								
V 10	-0.271	0.303	-.793**	-						
	0.393	0.338	0.002							
V 20	-0.056	0.154	-.831**	0.438	-					
	0.862	0.633	0.001	0.155						
V 30	-0.208	0.321	-.847**	0.498	.866**	-				
	0.517	0.309	0.001	0.1	0					
V40	-0.075	0.177	-.615*	0.062	.807**	.769**	-			
	0.817	0.582	0.033	0.849	0.002	0.003				
V 50	-0.51	0.521	-.813**	0.399	.787**	.778**	.696*	-		
	0.09	0.082	0.001	0.199	0.002	0.003	0.012			
V60	-0.18	0.338	-.684*	0.139	.756**	.772**	.930**	.752**	-	
	0.575	0.282	0.014	0.666	0.004	0.003	0	0.005		
ΔV_h	-.929**	.825**	-0.207	0.27	-0.137	-0.007	-0.162	0.256	0.005	-
	0	0.001	0.519	0.397	0.671	0.983	0.615	0.421	0.988	

**** Correlation is significant at the 0.01 level.**

*** Correlation is significant at the 0.05 level.**

Discussion

Based on the result from the current study, deceleration and acceleration of CoM did not correlate well with sprint performance. Only a trend toward significance at V 50 performance. That partially supports the assumption from previous studies (Payne et al., 1968, and Coh et al., 1999) that minimize braking effect could improve sprint performance. However, the effect of minimize braking effects might not play a significant role for sprint performance. Hunter, et al.

(2005) found the similar outcome, minimized braking effects only account for 7% sprint performance. Although testing distance and testing measurement were different between the current study and Hunter et al. (2005), the role of braking force did not show a great impact on sprint performance.

ΔV_h showed strong correlation with $A_{negative}$ and $A_{positive}$, although there was more ΔV_h during foot contact but did not impact sprint performance. Two of fastest sprinters that top speed at 10 m interval achieved over 10 m/s had two different ΔV_h pattern, one had relatively large value while the other had smaller one (0.88 m/s and 0.51 m/s respectively). Further study is needed to confirm these findings using a greater number of sprinters with different background and different sexes. Moreover, further studies also can focus on these variable correlates to technique differences.

Conclusion

The current study partially confirmed previous assumptions that "to achieve better sprint performance, sprinters should have short foot contact time with short braking and propulsion phases". However, the current study also found that some fast sprinters can also generate greater positive acceleration during propulsion phase to compensate larger negative acceleration during pervious braking phase. Further study is needed to confirmed current study outcome with using force platform, and also to recruit sprinters who have different training background to participate in the study.

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CHAPTER 4

Title: Using Kinetic Isometric Mid-Thigh Pull Variables to Predict D-I Male Sprinters' 60 M Performance

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Abstract

The purpose of the study was to determine the relationship of isometric mid-thigh pull kinetic variables including: peak force (PF), instantaneous force at 50, 90, 200 and 250 milliseconds (F@50, 90, 200 and 250 ms) rate of force development (RFD@ 50, 90, 200 and 250 ms) and impulse at 50, 90, 200, and 250 ms (IP @ 50, 90, 200 and 250 ms) to college male sprinters' 60 m running performance. Eleven NCAA Division I male sprinters participated in the study that included two testing sessions. The first session included sprint testing and the second session included isometric mid-thigh pull strength assessment. The results from current study indicated that explosive force production variables (F@ 50 ms, RFD @ 50 and 90 ms, IP @ 90 and 200 ms) showed strong correlations with 60 m running time and maximal running velocity; while the PF was not related to sprint variables.

KEYWORDS: sprint, peak force, explosive force production, rate of force development

Introduction

Strength is the ability to produce force (Stone, Sands, Carlock, and Callan et al., 2004). Force is a vector quantity, thus, strength could has a direction and magnitude (Stone, et al. 2004). Evaluation of skeletal muscle strength can be analyzed by force-time curves of isometric and dynamic muscle actions (Haff, Carlock, Hartman, Kilgore, Kawamoi, Jackson, Morris, et al., 2005). Variables that have been previously considered as important factors for sport performance include: peak force (PF), rate of force development (RFD), power output (PO) and impulse (IP) (Stone, et al., 2004; Haff, et al., 2005).

Sprinting is a cyclical movement. From a physical perspective, in order to achieve better sprint performances the ability of explosive force production and higher RFD during the limited time for overcoming body mass inertia is required (Tillin, Pain, and Folland, 2013). Thus, numerous sport scientists and coaches have used various testing protocols to explore and measure sprinters' ability to generate explosive force (Mero, Luhtanen, Vitasalo and Komi 1981; Wilson, Lyttle, Ostrowski and Murphy, 1995; Chunha, Fernades, Valamatos and Valamatos, et al., 2007; Bissas and Havenetidis, 2008; Requena, Badillo, Villareal and Ereline, et al., 2009; West, Owen, Jones, and Bracken, et al., 2011; Tillin, et al., 2013).

Among the various forms of testing, isometric force production measurements have been used quite often by sport scientists and coaches for assessing neuromuscular function in the field of sport science. Findings from Mero, et al. (1981) indicated that isometric peak force (IPF) was strongly related to sprinters' maximal running velocity in 100 m sprints. Wilson, et al. (1995) did not find any relationship between single joint isometric force production characteristics and 30 m sprint performance. Chuanha, et al. (2007) confirmed Mero's findings that IPF was correlated to sprinting performance in young athletes during the 60 m sprint. The same study also indicated that RFD was correlated to 60 m sprinting time, maximal running velocity and IPF. Somewhat contradictory, Bissas et al. (2008) did not find that IPF was related to 60 m sprinting performance and maximal running velocity (r=0.06) for trained athletes. However, the time to 60% of peak force correlated to maximal running velocity (r= - 0.73, p<0.05). Requena, et al. (2009) also reported no correlation between isometric force production variables and 15 m sprint performance in male soccer players. McGuigan, Newton, Winchester, and Nelson (2010) stated that isometric pull was a good test for strength related measurement but not for fast and velocity oriented movements.

However, the two of most recent studies, West, et al. (2011) indicated IPF from isometric mid-thigh pull relative to body weight was negatively correlated to 10 m sprint time, after analyzing 39 professional rugby players. In addition, the authors also found that force at 100 milliseconds (ms) and peak rate of force development were negatively correlated to 10 m sprint time. Similarly, Tillin, et al. (2013) reported that normalized peak force ≤ 100 ms was correlated to 5 m and 20 m sprint time for rugby players.

The lack of uniformity in results of the previously mentioned studies may be due to differences in participant backgrounds (e.g. non-athletes, field athletes, and sprinters, single vs. multi-joint) and methodology. As a result, questions remain in regards to the relationship of PF and sprint performance; as well as if isometric force assessments can predict dynamic movements effectively.

The purpose of the study was to determine the relationship of isometric mid-thigh pull (IMTP) kinetic variables (IPF, instantaneous force at 50, 90, 200 and 250 ms [F@50, 90, 200 and 250 ms], RFD and IP @ 50, 90, 200 and 250 ms) and Division I male sprinters' running performance variables (60 m running time and maximal running velocity).

Methods

Athletes participating in the current study included eleven Division-I male sprinters (body mass: 75.28 ± 6.39 kg, body height: 1.79 ± 0.04 m) on the East Tennessee State University track and field team. All athletes read and signed approved informed consent documents from University's Institutional Review Boards before participating in any testing. Testing was part of an ongoing athlete monitoring program.

Testing was completed on two separate testing sessions with at least 48 hours apart between testing sessions. The first session included the 60 m sprint test, while the second session included strength testing measured by an IMTP.

60 m sprint testing session: two sprints from standing position were performed by each athlete on an indoor 70 m long synthetic track with a lane width of 1.2 m. Before 60 m sprint testing, the athletes had sufficient time to warm up, which consisted of dynamic stretching. Afterward, two maximal effort 60 m sprint trials were measured. A 10 minute rest period between trails was given for participants to eliminate effects of fatigue. The sprint times were measured by an electronic timing gate system (Brower system, UT, US). Electronic timing gates were placed at 10 m intervals from the start line for 60 m (Figure 1). The results from timing gate system were used to calculate maximal running velocity (V-max) and overall 60 m running time (T 60). The best running time of the two trials was used for further analysis.

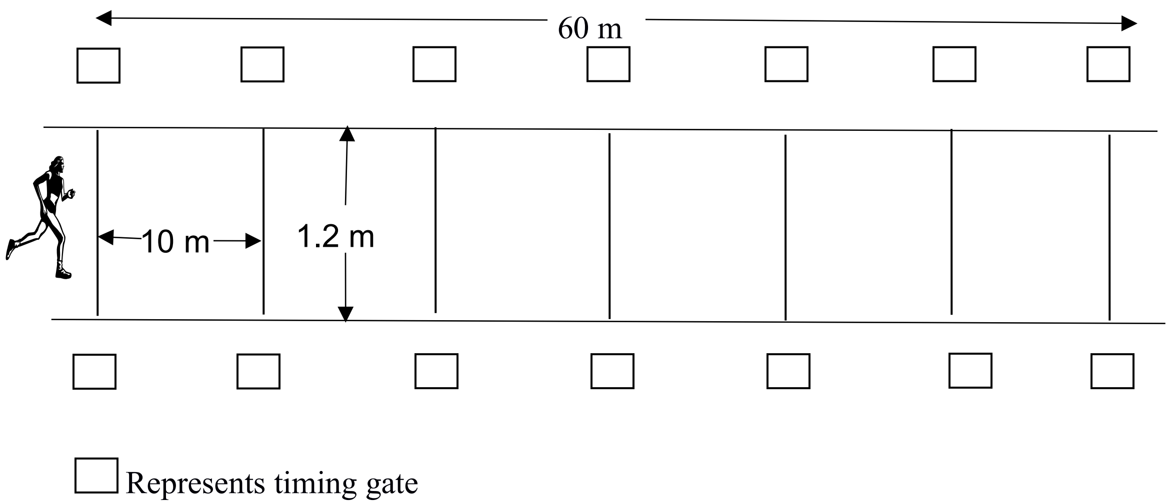

Figure 4.1. Sprint measurement.

During the strength testing session; athletes underwent a standardized warm up which consisting of 25 jump jacks, one set of five mid-thigh pulls with a 20 kg bar, and three sets of five mid-thigh pulls with a 60 kg load prior to testing.

Evaluation of strength was completed with a maximal effort multi-joint isometric contraction, an IMTP. The strength assessments were performed in a customized power rack and kinetic values were collected via a dual force plate setup (two separate 91 cm x 45.5 cm force plates, Roughdeck HP, Rice Lake, WI). Data were sampled at 1,000 Hz. The protocol, apparatus and positioning (Figure 2) were previously described by Haff and colleagues (1997).

The position for each isometric pull was established before each trial using goniometry, with each bar height corresponding to a 125±5º knee angle and a near-vertical trunk position. In order to ensure maximal efforts could be given without risking the loss of grip, athlete's hands were secured in position with weightlifting straps along with athletic tape.

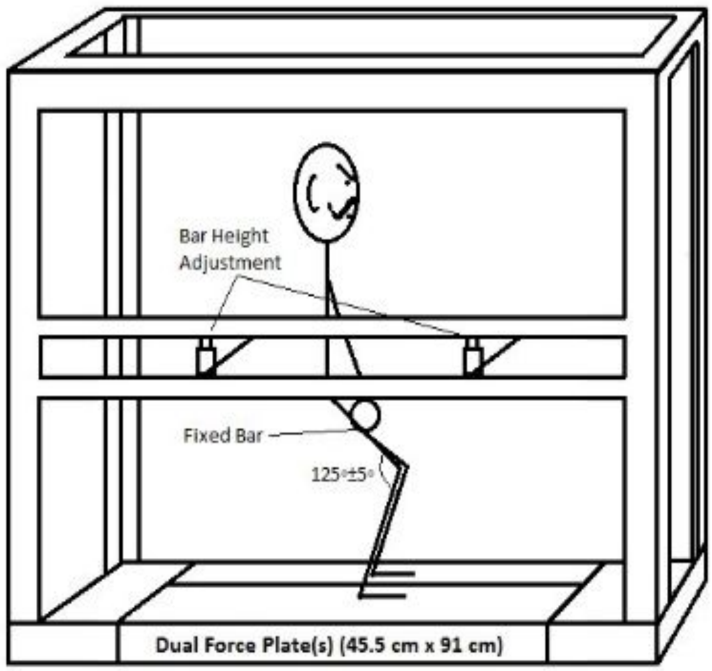

Figure 4.2. Isometric mid-thigh pull measurement.

Prior to maximal effort trials, athletes performed two familiarization and warm-up trials at 50% and 75% of perceived maximal effort. Afterward, athletes participated in a minimum of two maximal effort trials. Trials were considered successful as long as no countermovement of greater than 200 N was observed. In an effort to ensure maximum force and (RFD), athletes were coached to "pull as fast and as hard as possible". These commands were based on our previous experience and previous research indicating that the use of these instructions produces optimal results for PF and RFD (Stone. 2004). Athletes were given 2–3 minutes rest between each trial.

A customized LabVIEW program (Version 12.0, National Instruments Co., Austin, TX, USA) was used to both collect and analyze kinetic data obtained during the strength assessment.

Kinetic data obtained in the IMTP were: PF; RFD@50, @90, @200 and 250 ms, instantaneous force at 50, 90, 200 and 250ms (F@50, F@90, and F@250), and impulse at 50, 90, 200 and 250ms (IP@50, IP@90, IP@200 and IP@250). The 2 best trials (based on peak force) were averaged and used in the data analyses.

Statistics analysis

Intra-class correlation coefficients were used to test reliability of all kinetic variables (Table 1). Descriptive statistical analyses were conducted for all isometric mid-thigh pull and sprint variables. Relationships between variables were evaluated using Pearson product-moment correlation coefficients. The significance level was set at $p<0.05$.

Table 4.1.
Intra-class correlation coefficients.

Variables	**ICC**
PF (N)	0.92
F50 (N)	0.77
F90 (N)	0.85
F200 (N)	0.71
F250 (N)	0.93
RFD50 (N*/s)	0.67
RFD90 (N/s)	0.78
RFD200 (N/s)	0.64
RFD250 (N/s)	0.88
Impulse50 (N*s)	0.86
Impulse90 (N*s)	0.86
Impulse200 (N*s)	0.78
Impulse250 (N*s)	0.79

Results

Descriptive statistics of sprint and isometric mid-thigh pull variables are shown in Table 1. The correlation statistics showed that F@50 ms was strongly and inversely correlated to 60 m sprint time ($r= -0.54$, $p<0.05$); F@50 ms and F@90 ms was strongly correlated to V-max ($r=0.577$, $p<0.05$; $r=6.86$, $p<0.01$); RFD@50 ms and RFD@90 ms correlated to V-max ($r=0.605$, $p<0.05$; $r=0.742$, $p<0.01$, respectively); IP@90 ms and IP200 ms were strongly correlated to V-max ($r=6.03$, $p<0.05$; $r=0.547$, $p<0.05$). PF and scaled PF did not show statistically significant correlation to any sprint variables (Table 3).

Table 4.2.
Descriptive Statistics.

Variables	**Mean**	**S D**
PF	3029.83	517.34
F@50	1307.02	181.38
F@90	1696.78	352.68
F@200	2451.95	402.88
F@250	2641.81	432.18
RFD50	6131.10	3602.08
RFD90	7736.78	3739.78
RFD200	7257.43	2043.96
RFD250	6565.37	1706.51
IP@50	55.41	4.99
IP@90	115.91	15.73
IP@200	339.20	64.66
IP@250	465.19	90.02
T 60	7.05	0.30
V-max	9.60	0.44

Table 4.3.
Correlation coefficient matrix between sprint variables and kinetic isometric mid-thigh pull variables.

	PF	F@50	F@90	RFD50	RFD90	IP@90	IP@200
T 60	0.4	-0.382	-0.27	-0.540*	-0.373	-0.085	-0.287
V-max	-0.174	0.577*	0.686**	0.605*	0.742**	0.603*	0.547*

*. Correlation is significant at the 0.05 level.
**. Correlation is significant at the 0.01 level.

Figure 4.3. Relationship between Vmax and F@90 ms (N)

r=0.742
p<0.01

Figure 4.4. Relationship between Vmax and RFD@90 ms (N/s)

Discussion

The aim of the current study was to determine the relationship of isometric force production characteristics to D-I male sprinters' sprinting performance variables. The current study found that F@50 ms was strongly and inversely correlated with T 60 ($r= -0.54$, $p<0.05$); F@50 ms and F@90 ms were strongly correlated with V-max ($r=0.577$, $p<0.05$; $r=6.86$, $p<0.01$); RFD@50 ms and RFD@90 ms were correlated with V-max ($r=0.605$, $p<0.05$; $r=0.742$, $p<0.01$, respectively); IP@90 ms and IP200 ms were strongly correlated with V-max ($r=6.03$, $p<0.05$; $r=0.547$, $p<0.05$). The PF and scaled PF did not show statistically significant correlation with any sprint variables.

The results of the current study agree with West, et al. (2011) that the initial 100 ms force production from the IMTP correlated with short sprint performance. The current study found that F@50 ms is strongly correlated with T 60.

Different from the reports of McGuigan and Winchester (2008), the current study found that RFD@50 and 90 ms correlated strongly with V-max performance. One of possible reasons for a different outcome would be the differences in calculation of RFD. The current study calculated instantaneous force value at 50, 90 200 and 250 ms. However, the way of calculation of RFD in McGuigan and Winchester (2008) was not clearly indicated. Another reason could be the differences in the testing method. McGuigan and Winchester (2008) tested vertical jumps and the current study tested the 60 m sprint. Although vertical jumps and sprints share similarities in that both of them were explosive movements, the time for sprinters to apply force on the ground (< 100 ms) was shorter than the contact time for vertical jumps (≥ 300 ms). It is not possible to achieve peak force during that short amount of time, but the ability to increase RFD becomes very important within 100-200 ms (Aagaard, Simonsen, and Andersen, 2002). Thus, it is not surprising that sprinters' RFD@50 and 90 ms performance correlated with V-max in the current study. West et al. (2011) support this finding, as they found that 10 m sprint times inversely correlated with the initial 100 ms force production from professional rugby league players, which indicates that the ability of produce larger forces during a short period of time is an important factor for sprint performance. The participants' training backgrounds were different. McGuigan and Winchester (2008) recruited football players in their studies, while the current study had collegiate level sprinters. Usually, football players have a larger body mass compare to sprinters. Body mass plays an important role for sprint performance. Moreover, the strength and conditioning backgrounds were quite different between the two sports; sprinters generally trained at more explosive-oriented movements, while football players trained at more strength-oriented movements.

The current study agrees with previous studies (Chuanha, et al., 2007; Bissas and Havenetidis, 2008; Tillin, et al., 2013) that RFD showed statistically significant correlation with sprint times and maximum running velocity. When participants are sprinting, the ground contact time is less than 100 ms on average during the top speed. Therefore those sprinters who could produce larger forces on the ground during a short period of time may lead to better 60 m sprint performance.

One important finding in the current investigation was the statistically significant correlation of the IP@ 90 ms and the IP@ 200 ms with maximum sprint velocity (see Table 2). According to Aagaard et al. (2002), the IP as the time integrated moment of force is identical to the kinetic momentum during limb movement. Limb momentum is defined by $I * \omega$, as I is the moment of inertia of the limb and ω is the instantaneous rotation velocity. Mann and Herman (1985) stated that compared to the eighth place sprinter in the 1984 summer Olympic games, the gold and silver medalists showed faster rate of thigh rotation during the foot contact phase. A later study from Harris, et al. (2008) also reported that IP relative to the body mass during squat jumps with a load from 20% to 90% 1 RM on a smith machine negatively correlated with 30 and 40 meter sprint times (r= -0.31 to r= -0.47). This supports the assumption of Aagaard, et al. (2002) that RFD play a more important role for fast movements. Thus, IP is an important indicator for sprinters' performances and training programs. Based on the current study, IP is a more reliable variable; moreover, it represents the ability to generate force during the certain time window. It is a determinant factor for sprint performance since sprinters have about 100 ms to generate force during the foot contact phase.

The result from the current study is contrary to previously reported data from several studies including Mero, et al. (1981), Perkins (1995), and Chuanha, et al. (2007). This difference may be due to the participants' training and competition backgrounds and the testing protocol differences among the studies. Mero, et al. (1981) compared sprinters with different training backgrounds in their study. The sprinters who competed at higher levels of competition showed a greater relationship to peak force characteristics. However, Perkins (1995) and Chuanha, et al. (2007) either combined male and female participants or compared athletes and non-athletes in the study that might not be as precise or valid to represent the correlation of strength with sprint performance. Mero, et al. (1981) used isometric single joint dynamometer, while Perkins (1995) and Chuanha, et al. (2007) used isometric leg press measurements. Compared to these previous studies, the current study used IMTP. Previous studies (Stone, et al., 2003; McGuigan and Winchester, 2008; West, et al., 2011) demonstrated that IMTP is a reliable and valid measurement for maximal strength performance (1 repetition maximum [1 RM]). Therefore, further studies may be needed to confirm the results from the current study.

To better explore the role of PF for sprint performance, longitudinal studies could provide more evidence. Previous researchers (Mero, et al., 1981; Young, et al., 1995; Perkins, 1995; Cronin and Hansen, 2005; Chuanha, et al., 2007; West, et al., 2011) provided the relationships between PF and sprint performance. However, correlation analyses are of limited value in identifying the "cause and effect" relationship between PF and sprint performance (Cronin, et al., 2005). A review paper from Cronin (2007) indicated that most of the studies found significant strength change gains without improvement in the sprint performance. Of all the studies, only one (Blazevich and Jenkins, 2002) recruited junior level track & field athletes. The rest of the studies reviewed by Cronin (2007) were either recruiting recreational or field players. Those athletes might not represent the characteristics of sprinters, such as body mass and height differences among them. Moreover, Blazevich and Jenkins (2002) reported improvement in both strength and sprint performance. However, the study recruited novice level athletes and only lasted 8 weeks. The effects of long term training for PF and its relationship for sprinters' running performances are still unclear.

Based on the latest longitudinal studies (Hoffman, et al., 2011; Jacobson, Conchola, Glass, and Thompson, 2013) that focused on NCAA III and Division I football players' strength and sprint performances, they reported that all strength and power variables increased from the first to fourth competition years, but sprint performance did not. Sprint performance only showed improvement at the third year. There was no improvement of sprinting performance at the fourth year. However, if we take a look at strength levels between the third and fourth years, the strength did not improve too much either. This phenomena might be related to no improvement of sprint performance at the fourth year. Thus, how training affects PF and its relationship with sprinters is still unknown. Further study is needed to explore the long term effects of training for both strength and sprint performances.

In addition to PF and sprint performance, further longitudinal study should also focus on the RFD and sprint performances. Based the current and previous studies, the RFD may be essential for sports performance and functional tasks (Aagard, et al., 2002). Anderson, Anderson, Zebis and Aagard (2010) stated that early (<100 ms) and late (>100 ms) phases of RFD were related to responses from engaging in resistance training. Oliveira, Oliveira, Rizatto, and Denadai (2013) indicated that early phase RFD is influenced by intrinsic muscle contractile properties and neural drive, while late phase of RFD is influenced by muscle cross sectional area. Thus further study might focus on how sprinters' RFD response to resistance training, consequently, how RFD changes is related to sprint performance during the season.

Conclusion

The current study demonstrates that isometric force production characteristics (F@ 50 ms, F@ 90 ms, RFD 50 ms, RFD 90 ms, IP 90 ms and IP 200 ms), assessed from the IMTP position, are related to D-I male sprinters' 60 m sprinting performance. Sport scientists and coaches should focus on the development of sprinters' ability to produce explosive force through training and monitoring. Further study might investigate the relationship of IMTP pull force production characteristics to sprint performance in sprinters with different competition levels (elite vs. non-elite), as well as the role of maximum strength in sprinters' performance at different competition levels.

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CHAPTER 5

Title: Influence of Whole and Lower Angular Momentum Cancellation during Terminal Swing Phase To Sprint Performance

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Abstract

Sprinting is a cyclic movement. To pursue a better sprint performance is interest of most sprinters, coaches and sports scientists. Current study is to determine how body segments interact during terminal flight phase is related to maximal velocity running performance. Overall twelve D-I male sprinters participated in the study. Each sprinter had two trials of maximal effort to run 60 meters in the indoor track. 3-D movement was captured by Vicon Nexus between 50 meter and 57.5 meter. A 14-segment mathematical model was built to calculate whole-body angular momentum. Whole and lower body angular momentum cancellation coefficients were calculated and used to further analysis their correlation to maximal running velocity performance. Based on the results, no correlation was observed between whole and lower body angular momentum cancellation coefficients and maximal running velocity performance. However, a certain trend of statistical significance between lower angular momentum cancellation at frontal plane and maximal running velocity performance was observed. Further study is needed to confirm the results of current study.

Introduction

Sprinting is a cyclical movement. Pursuing faster running speed is one of the most interesting topics for coaches, athletes and sports scientists. Based on velocity time curve, sprint running is divided into an acceleration phase, maximal velocity and velocity maintenance phases. However, some researchers and coaches consider block start as one single phase. (Mero, Komi & Gregor 1992).

After the acceleration phase, sprinters gradually attain an upright position and achieve their maximum velocity. From support leg analysis perspective, previous studies that either mathematical models or biological experiments found fast sprinters could produce greater force during a short period of time, especially during 100 milliseconds window (Miller, Umberger & Caldwell 2012; Morin, Bourdin, Edouard, Peyrot, Samozino et al., 2012; Tillin, Pain, Folland 2013; Sha, Bailey, McInnis, Sato, Stone 2014). Moreover, Morin et al. (2012) indicated that fast sprinters could produce force at more horizontal orientation related to resultant force. Thus, to achieve fast sprint performance at maximal running velocity phase requires sprinters to produce greater force during a short period of time at horizontal orientation.

From swing leg analysis perspective, (Dilman 1970; Vardaxis 1988) fast and slow sprinters show similar movement patterns, however, the fast sprinters showed higher peak values that occurred at the earlier time during swing phase, especially during the terminal swing phase. The fast sprinters showed fast leg retraction movement before foot contact with floor. Many authors believed this might be is related to minimized velocity losses during the subsequent foot contact phase. Based on the latest study, this leg retraction movement related to impact during the subsequent foot contact phase. Therefore, swing leg movement especially leg retraction movement during terminal swing phase, can affect subsequent foot contact phase.

Several studies that either focus on support leg (Hunter, Marshall & McNair 2005; Morin et al. 2012) or swing leg (Dilman1970; Chapman and Caldwell 1983; Mann and Herman 1985; Vardaxis 1988; Ae, Ito, Suzuki 1992) performance provide invaluable information for short sprint events; however, human body as whole working system, there is interaction between each segment during walking and running movement (Hinrich 1984; Herr and Popvic 2008; Bennett, Russell, Sheth, Abel 2010). Thus, overall whole body angular momentum were not large. Raibert (1986) stated that before foot contact with the floor, if different moving direction of biped angular momentum could cancel out each other during late flight phase, then body system could better preserve whole body angular momentum during the subsequent foot contact phase and to achieve better running performance. However, this assumption has not been confirmed during sprint events. Based on the previous studies, (Mann et al. 1985; Ae et al. 1992; Dillman 1970) during the terminal swing phase, fast sprinters showed greater leg retraction (forthcoming supporting leg) and forward trail leg swing velocities than slower sprinters. Moving lower limbs' in opposite direction (one is moving forward and the other is moving backward) at a faster rate lead to more angular momentum cancel out each other. That may assist them to better preserve whole body angular momentum during subsequent foot contact phase. Hopper (1973) indicated that good timing of the body segments' movements could influence force production during the foot contact phase. Currently, there is only one study (Hinrich 1987) analyzed angular momentum during a running event. It demonstrated that the lower limbs are the primary contribution to the running performance. However, due to the purpose of the study, the author did not calculate the angular momentum cancellation between the lower limbs and how this cancellation related to sprint performance.

Thus the purpose of the study is to determine the relationship of whole and lower body angular momentum cancellation during the terminal flight phase to the maximal running velocity performance in D-I male sprinters.

Methodology

Participants

Twelve male (body mass: 75.28 ± 6.39 kg; body height: 1.79 ± 0.04 m; 60 m running time: 7.16 ± 0.37 s; 7.5 m interval: 0.805 ± 0.04 s; age: between 19 to 21 years old) NCAA Division I sprinters (East Tennessee State University Track Team) participated in the study. The data was part of an ETSU athletes monitoring program. The participants read and signed University approved informed consent documents prior to participation in this study.

Sprint measurement

During the 60 m sprint testing session two sprints from standing position were performed by each participant on an indoor 70 m long synthetic track with a lane width of 1.2 m. Before 60 m sprint testing, the participants had sufficient time to warm up, which consisted of dynamic stretching. Afterward, two maximal effort 60 m sprint trials were measured. To eliminate effects of fatigue, a 10 minute rest period between trails was given for participants. The sprint times were measured by an electronic timing gate system (Brower system, UT, US). Electronic timing gates were placed at 10 m intervals from the start line for 60 m. Additionally, a pair of timing gates were set at the 57.5 m mark (Figure 1). Sprint time of the 7.5 m interval between 50 m and 57.5 m interval were used for further analysis.

Motion Capture

Kinematic data were collected by a Vicon Nexus 1.8.5 video graphic and analog data acquisition system (Vicon, UK) with six cameras at a sampling rate of 240 frames/s. Reflective markers were placed bilaterally (shoulder, upper arm, elbow, forearm, wrists, finger, thigh, knee, shank, ankle, heel and toe) using a Vicon Full Plug-in-gait marker set. Diameters of reflective markers were 20 mm. The calibration volume was 7.5 m long, 1.2 m wide and 1.9 m high. Running direction corresponded to the X axis, the Y was lateral axis and the Z was vertical axis. Kinematic data were low pass filtered with a fourth Butterworth filter with cutoff frequencies of 15 Hz (Yu. 1989). The setup of cameras were shown at figure 1 and figure 2. An analyzable trial was a trial in which kinematics data of two running steps were recorded successfully by the system.

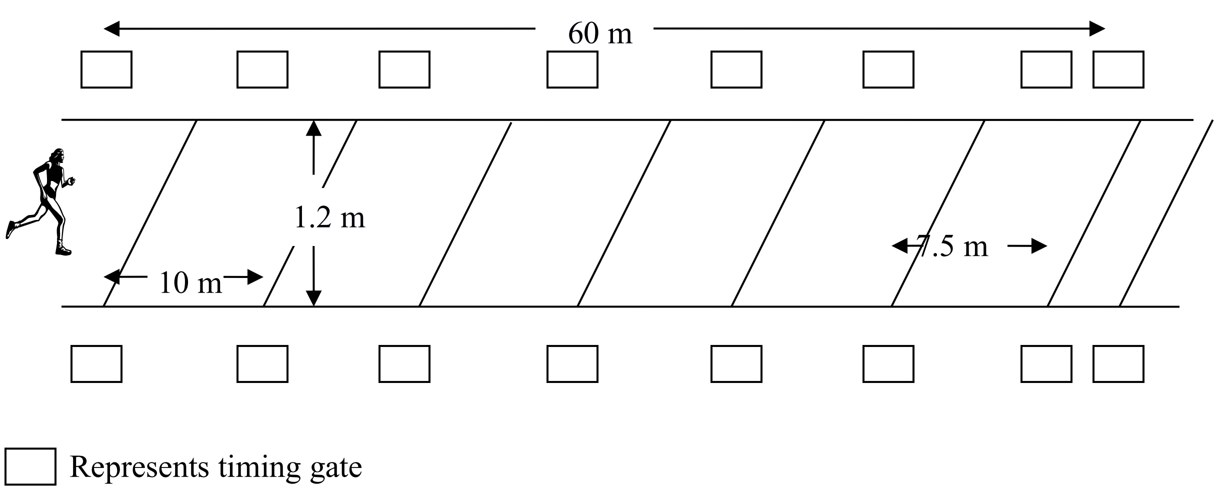

Figure 5.1. Sprint measurement

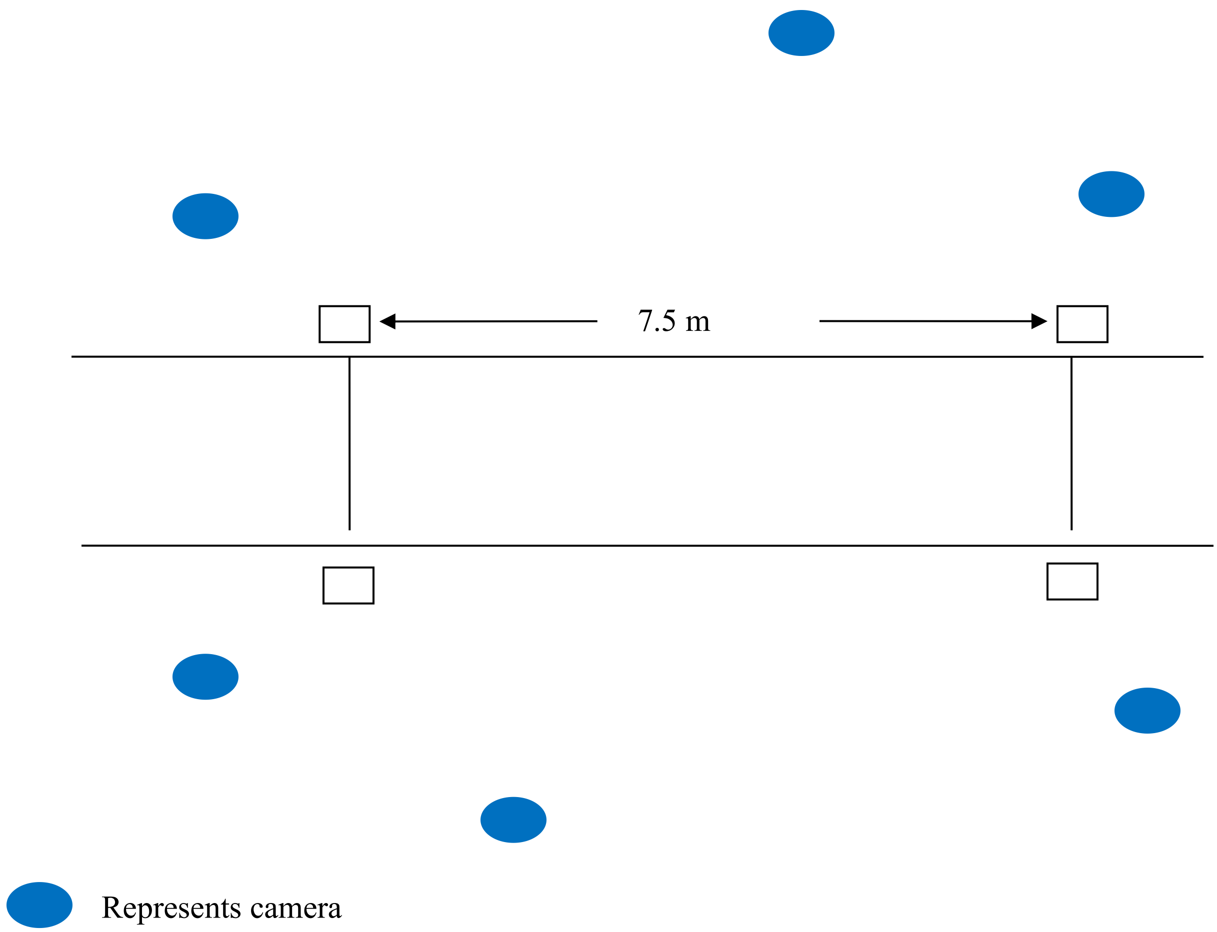

Figure 5.2. Kinematic data measurement from 50 m and 57.5 m.

Phase determination

According to Yu et al (2008), the time of a foot strike was defined as the time represented by the first frame in which the vertical coordinate of the heel or toe became a constant. The time of a toe off was defined as the time represented by the frame immediately after the last frame in which the vertical coordinate of the toe was constant. The time period between a foot strike and the subsequent toe off of the same foot was referred to as the foot contact phase. The time period between a toe off and the subsequent contralateral foot strike was referred to as a flight phase. Based on Hunter et al. (2005), four frames (1/240*4≈ 0.017 s) before the foot contacts with floor were the criteria to define the terminal swing phase.

Angular momentum calculation

A 14-segments of human kinematic model was created by Vicon BodyBuilder. Selective anthropometry data were measured. Details of the calculation of whole body angular momentum were described below:

The angular momentum of a body is a vector quantity which represents the magnitude and the direction in which the body rotates about a reference point. The angular momentum of each segment will be computed as the sum of the local angular momenta (the segment revolving about its own CoM) and a transfer term (the result of the CoM of the segment moving relative to the body CoM). All the data were transferred and calculated by Matlab. These terms are defined for the segment as:

Where is the moment of inertia tensor of the segment; is the angular velocity vector; and are the relative position and velocity of the segment's CoM to the whole-body CoM, respectively; is the linear momentum of the segment; m_i is the mass of the segment.

Whole body angular momentum were normalized with body mass and body height in the study. The equation that used to normalized for body mass and body height was listed below:

is normalized whole body angular momenta, and is non-normalized value; and are participants ‘body mass and body height.

According to Dapena (1978) that ignoring rotations of non-trunk segments about their longitudinal axes involves little error in the computation of the angular momentum of the whole body about its center of gravity or about any inertial point. Center of mass and moment of inertia of each body segment was calculated from De Leva (1996) in table 1 and table 2.

Due to differences between current participants and the mean data that was used in De Leva (1996), the method from Depena (1978) was used to adjust body segment's moment of inertia value:

$$=$$

The formula, and are the participant's body mass and body height from the current study. , and were mean values of segment's moment of inertia, body mass and body height from De Leva (1996).

Table 5.1.
Mean body segments center of mass parameters from De Leva (1996)

Segment	Mass (% of total body mass)	Location of center of mass (% of segment length to proximal endpoint)
Head	0.0694	0.4024
Trunk	0.4346	0.5514
Upper arm	0.0271	0.5772
Forearm	0.0162	0.4574
Hand	0.0061	0.7900
Thigh	0.1416	0.4095
Calf	0.0433	0.4459
Foot	0.0137	0.4415

Table 5.2.
Parameters from De Leva (1996)

Segment	**Moment of Inertia about Axis (kg*m^2)**	**Moment of Inertia about Transverse Axis (kg*m^2)**	**Moment of Inertia about Longitudinal Axis (kg*m^2)**
Head	0.0272	0.0294	0
Trunk	1.2422	1.0808	0.3250
Upper arm	0.0127	0.0114	0
Forearm	0.0065	0.0060	0
Hand	0.0013	0.0009	0
Thigh	0.1998	0.1999	0
Calf	0.0385	0.0371	0
Foot	0.0013	0.0040	0

Angular momentum cancellation

The method used to calculate whole and lower body angular momentum cancellation coefficient was adopted from Bennett et al. (2010), the formula that listed below:

$$\boldsymbol{K} =$$

The formula was created to evaluate the degree that the angular momenta of the body segments cancel each other at three planes. If there was no net angular momentum, all segments cancelled each other out perfectly, k= 1. If there was no cancellation, then the two terms in the numerator are equal and k = 0. The mean values from the two steps of whole and lower body angular momentum cancellation coefficients were used in further analysis.

Statistical analysis

Pearson correlation coefficient was used to test reliability of variables from two steps. In addition, Pearson correlation coefficient was also to test the relationship of sprint performance and angular momenta variables. The significance level was set at $p<0.05$.

Results

Table 5.3.
Normalized whole body angular momenta at frontal, sagittal and transverse plane from two steps (left and right side respectively).

	Mean	Std. Deviation
Frontal L	-0.0036	0.01576
Frontal R	0.0094	0.01504
Sagittal L	0.0303	0.01338
Sagittal R	0.036	0.00826
Transverse L	0.0124	0.00487
Transverse R	-0.0107	0.00506

Table 5.4.
Whole body angular momenta cancellation from two steps (left and right respectively).

	Mean	Std. Deviation
$W_{Frontal}$ L	0.643	0.18873
$W_{Frontal}$ R	0.5458	0.24126
$W_{Sagittal}$ L	0.8333	0.05012
$W_{Sagittal}$ R	0.8113	0.03503
$W_{Transversel}$ L	0.8416	0.09117
$W_{Transverse}$ R	0.9005	0.07483

Table 5.5.

Lower extremities angular momenta cancellation from two steps (left and right respectively).

	Mean	Std. Deviation
$L_{Frontal}$ L	0.5653	0.35561
$L_{Frontal}$ R	0.3734	0.28771
$L_{Sagittal}$ L	0.7939	0.05545
$L_{Sagittal}$ R	0.7793	0.04356
$L_{Transverse}$ L	0.0094	0.02622
$L_{Transverse}$ R	0.0175	0.04159

Table 5.6.

Mean of whole body and lower body angular momenta cancellation coefficients.

	Mean	Std. Deviation
$W_{Frontal}$	0.5944	0.19697
$W_{Sagittal}$	0.8223	0.03292
$W_{Transversal}$	0.8711	0.05878
$L_{Frontal}$	0.4694	0.31006
$L_{Sagittal}$	0.7866	0.0327
$L_{Transverse}$	0.0135	0.0246
T57	0.8042	0.041

Table 5.7.

Correlation between whole body and lower body angular momentum cancellation coefficients and maximal running velocity performance.

	$W_{Frontal}$	$W_{frontal}$	$W_{Transversal}$	$L_{Frontal}$	$L_{Sagittal}$	$L_{Transverse}$	T57
$W_{Frontal}$	1						
$W_{Sagittal}$	-0.115	1					
	0.361						
$W_{Transversal}$	0.118	0.246	1				
	0.357	0.22					
$L_{Frontal}$	.658*	-0.45	0.299	1			
	0.01	0.071	0.172				
$L_{Sagittal}$	-0.101	.936**	0.344	-0.466	1		
	0.377	0	0.137	0.063			
$L_{Transverse}$	.620*	-0.398	0.047	.603*	-0.461	1	
	0.016	0.1	0.443	0.019	0.066		
T57	-0.325	0.298	-0.029	-0.425	0.233	0.118	1
	0.152	0.174	0.465	0.084	0.233	0.358	

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Descriptive data were shown in tables 3 through 6. Due to only two stride steps were captured during the current study, normalized whole body angular momenta were not used in statistical analysis. In addition, there was no correlation of kinematic data was observed between the two steps indicated a certain asymmetry exists between the left and right sides. The current study only listed it as descriptive data. The Mean value of whole and lower body angular momentum coefficients were used for further analysis.

Descriptive of normalized whole body angular momenta were listed in table 3. Only two steps were captured and calculated in the study. Normalized whole angular momenta in the frontal plane showed the small side to side motions, in X direction. Thus, the direction of normalized whole body angular momenta at frontal plane were opposite from each step, the absolute magnitude of angular momenta were almost identical. Transverse angular momenta had a similar pattern. The direction of normalized whole body angular momenta from sagittal plane maintained the same direction through the two steps. The largest values of whole body angular momenta from sagittal plane movements, Y direction. The smallest values were from transverse plane in Z direction that because of the upper body and lower body have opposite movement directions, so their angular momenta cancel each other off.

Lower extremities' angular momentum were also follow the same pattern with whole body angular momentum. The largest value of angular momenta were from sagittal plane. The smallest values were from transverse plane.

The mean value of whole and lower body angular momentum cancellation coefficients from two steps were used for further analysis. Due to purpose of the study, whole and lower body angular momentum cancellation coefficient was not normalized because of calculation of cancellation coefficients would range from 0 to 1.

Whole body angular momentum and lower extremities angular momentum cancellation coefficients were listed in table 5. The whole body angular momentum cancellation coefficient showed higher values at sagittal and transverse planes (0.8223 and 0.8711 respectively). In contrast, the lower body angular momentum cancellation coefficient only showed higher value at the sagittal plane. The smallest cancellation coefficient was lowest from the transverse plane.

Correlation of whole body and lower body angular momentum cancellation coefficients with sprint time were listed in table 7. Only the lower body angular momentum cancellation coefficients at the frontal plane showed a certain trend of statistical significance with sprint time. Other variables did not show statistical significance with sprint time.

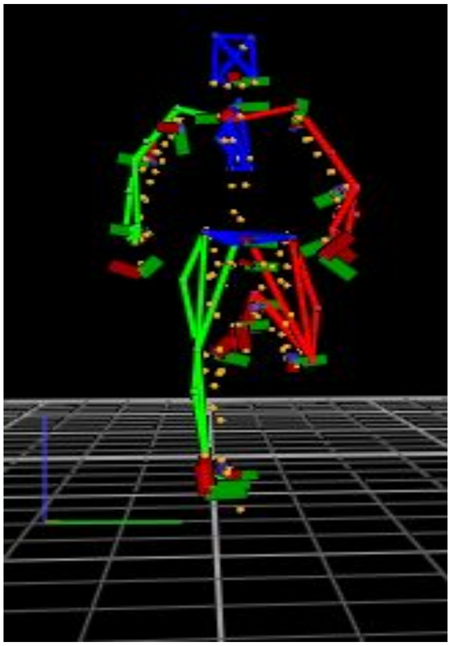

Figure 5.3. Frontal plane

Figure 5.4. Sagittal plane.

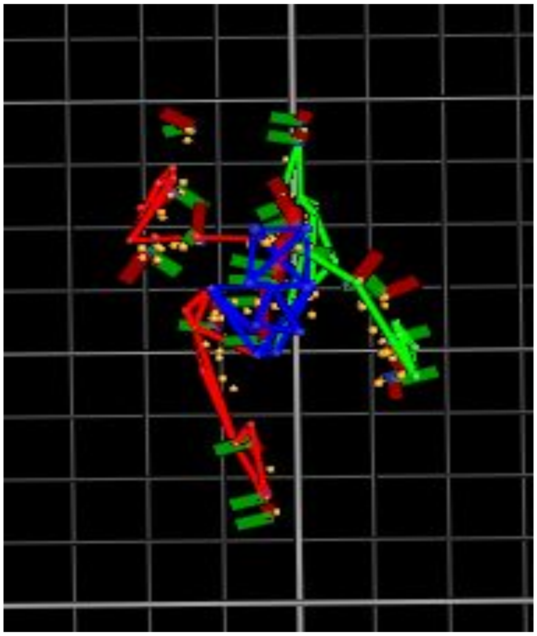

Figure 5.5. Transversal plane.

Discussion

The current study showed consistency with Hinrichs (1987), as sprinters running through the capturing area, they showed positive and negative whole body angular momenta during each step at frontal plan. The whole body showed little swaying side to side during both flight and foot contact phases. Since angular momentum at frontal plane was primary related to moment arm and vertical ground reaction force, as moment arm did not change too much during each running step that indicated that vertical forces were generated and went through the CoM during the foot contact phase.

This study agrees with previous studies (Hinrichs 1987; Bennet et al. 2010 ;), the largest value of whole body angular momenta were from sagittal plane. Similar to frontal as moment arm did not change too much during each step. That indicated horizontal force passed through CoM during the foot contact phase. It was consistent with previous studies (Hinrichs 198; Herr and Popvic 2008; Bennett et al. 2010) that most part of whole body angular momenta were contributed from lower body. The arms contribute only small part to the whole body angular momenta at the sagittal plane. More details of contribution of each body segment during running were described in Hinrichs (1987).

At the transverse plane, the current study agrees with previous studies (Hinrichs 1987; Herr and Popvic 2008; Pontzer et al. 2008; Bennet et al. 2010), there was interaction between the upper bodies especially arms and lower bodies. It is very clear that combine all the individual segment's angular momentum, the whole body angular momenta were very small.

However, the current study can not confirm if the arms were active or passive during sprint performance. Based on the previous studies (Hinrichs 1987; Herr and Popvic 2008; Bennet et al. 2010; Hammer, Seth & Delp 2010) the arms a play major role to counteract the angular momenta generated from lower body at transverse plan, even before foot contact with the floor. The other theory was the arms were passive movement during walking and running movements (Pontzer, Holloway, Raithlen, Lieberman 2008). Further study may be needed to confirm this during a sprint event.

Due to equipment limitation, the current study only captured two sprint strides. Based on the whole body angular momenta, sprinters showed some asymmetries between the left and right side steps. This result showed consistency with previous studies (Hinrichs 1987; Exell, Gittoes, Irwin, Kerwin 2012). There are a certain differences and asymmetries between the two steps, but the differences were small and did not impact with sprint performance.

Consistent with previous studies (Herr and Popvic 2008; Bennet et al. 2010) that the whole body cancellation coefficient was lowest (0.5944) at the frontal plane among the three planes. That indicated all the segments did not cancel out each other at frontal plane, especially between the upper and lower bodies. If look at the value of the whole body angular momentum from the two steps, it clearly indicated that sprinters had minimal swing side and side movement which minimize range of the angular momentum. The mean value of angular momenta at frontal plane were the smallest among three planes could explain this phenomena.

The lower body angular momentum cancellation coefficient was 0.4694 and showed a certain trend with sprint performance. It was a little surprising to see this result, although it did not achieve statistical significance. As the body left the ground, neglecting the air resistance, the whole body angular momentum was decided by med-lateral force from the previous foot contact phase and the magnitude kept constant. However, interactions between the two lower limbs may influence subsequent foot contact phase. During the flight phase if interactions of angular momentum not cancelled out appropriately, the rest of angular momentum needs to be absorbed during the foot contact phase. Previous studies showed this free limbs related to the decreasing impact (Yu 1996; Huang, Liu, Wei, Li, Fu et al., 2013) during the foot contact phase. The other explanation was that if the forthcoming support leg moving backward while the trail leg moving forward along with the pelvis rotation is related to hip joint force and the rate of energy change during the subsequent foot contact phase and so forth related to the stride frequency (Chapman and Caldwell 1983). The two fastest sprinters lower body angular momentum cancellation coefficients were showed higher value 0.6 and 0.8 respectively supports this finding. Further study might needed to confirm this.

For a long time coaches have believed that sprinters should limit their arms and legs limit lateral movements of their arms and legs could improve sprint performance. The current study partially support this view, however, the most important thing is the appropriate timing of lower legs interactions during the terminal swing phase. Since body left ground, the whole body angular momentum would not be changed. The magnitude of whole angular momentum were decided by the force and moment arms during the foot contact phase. Some sprinters like to fully extend the support leg during the terminal foot contact phase, however, this full extended support leg would not produce significant extra effective horizontal force (Mann 2011). Moreover, due to the flight time is limited and support leg position during terminal foot contact phase, full leg extension would influence subsequent leg swing forward and backward performance; and influence interactions between the lower body segments during the terminal swing phase and sprint performance.

Therefore, coaches should focus on the sprint technique training during maximal running velocity . Moreover, Mann (2011) indicated to achieve this certain technique, sprinters should have a strong and explosive force production ability. Although Mann did not conduct studies to prove this, the other studies (Mero and Komi 1986; Alexander 1989; Mero et al.1992; Kale, Asci, Baryak, Acikada 2008; Sha et al. 2014) supported his assumption. Thus, in order to improve maximal running velocity performance, sprinters must improve strength variables (especially ability to produce to explosive force during short period of time) and technique training as two primary training goals.

The Whole and lower body angular momentum cancellation coefficients showed the highest value in the current study. During the maximal velocity phase, the arms swing back and forth alternatively. Angular momentum from the arms could cancel out each at the sagittal plane due to opposite movement direction. Similarly, the legs also showed the same mechanism, the cancellation coefficients were 0.7866. The trunk and head also had little forward and backward movement. According to Hinrich (1987) it played an important role for sprint performance.

At the transverse plane, the whole body angular momentum cancellation coefficient had largest value among the three planes. Although the current study could not confirm how the upper body, especially the mechanics of the arms (active or passive) to counteract angular momentum from the lower body. However, the current study is consistent with previous studies (Hinrichs 1987; Herr and Popvic 2008; Bennet et al. 2010; Hammer et al. 2010) about the interactions between the upper and lower bodies. That is because of the whole body angular momentum cancellation coefficient was 0.8711 almost achieved 100%, while the lower body angular momentum cancellation coefficient was almost zero (0.0135). It clearly indicated the interaction between the upper and lower bodies to cancel out each other's angular momentum.

The current study did not show that either the whole body or lower body angular momenta cancellation coefficient correlated to sprint performance. This outcomes did not support the previous assumption from Raiber. Perhaps, one of reason is sprinters participated in the current study were in homogeneities. However, the lower body angular momenta cancellation coefficient at the frontal plane showed certain trends with sprint performance might demonstrate the timing of lower body movement is related to sprint performance. Especially, when comparing the three fastest sprinters with running velocity over 10 m/s, their lower body angular moment cancellation coefficient were all higher than the rest of the participants. Thus, further study might be needed to confirm this with sprinters in heterogeneous groups.

Limitations and Future Study

Due to equipment limitation, the current study only captured 2 steps from the maximal velocity phase. In addition, the sprinters that participants in the current study were college level sprinters with similar sprint performance; further studies are definitely needed to confirm the current study results with more sprinters with a different training background, and also include a force platform in the study.

Conclusion

The current study did not find the correlation of whole body angular momentum cancellation during the terminal swing phase with maximal velocity running performance. However, a certain trend of lower body angular momentum cancellation and maximal velocity running performance was observed. That partially confirms the coaching philosophy to limit sprinters lateral movement during sprint. More importantly coaches and sprinters should focus on appropriate sprint technique—limit fully leg extension during the terminal foot contact phase. In order to achieve this, both appropriate technique and strength (the ability to produce explosive force during a short period of time) training should be included in the training program.

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CHAPTER 6

SUMMARY AND FUTURE INVESTIGATIONS

The first study showed that fast sprinters cannot eliminate the braking phase and subsequently can't decrease CoM velocity loss during the initial foot contact phase. Thus, consistent with several previous studies, faster sprinters have to withstand braking phase during the foot contact phase. Coaches and sport scientists may not need to over-emphasize this during training.

The second study showed consistency with previous studies that the ability to produce greater force during a short period of time is one of the primary indictors for better sprint performance, especially ability to produce force within 100 ms. However, the current study did not show that maximal strength variable correlate with any sprint variables. Thus, coaches and sport scientists should focus on exploring and determining appropriate training plans to enhance sprinters' ability to produce force during a short period time.

The last part of the study analyzed the angular momentum cancellation coefficient and its correlation with sprint performance. The study did not show statistical significance between them. However, a certain trend was observed between the lower body angular momentum cancellation coefficient at the frontal plane and sprint performance. This result was partially supporting previous assumption that a good timing of body segments' movement prior to the foot contact phase is correlated with sprint performance.

There were several limitations. The current study only recruited D-I male sprinters, thus, the number of the sprinters was relatively low. In addition, their training backgrounds were similar. Thus, the current study might not represent higher training level male sprinters. A second limitation was due to the number of cameras, the distance that being captured was only

7.5 meters long, moreover, due to the testing taking place in a previously built stadium, force platform was unable to be inserted into the track. Thus, further studies are needed to recruit more sprinters with different background, ideally with force flatform data and longer running distance that can be captured and analyzed. In addition, the long-term training effects for the ability of producing explosive force during a short period time and sprint performance need to be investigated.

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APPENDICES

APPENDIX A: ETSU Institutional Review Board Approval

East Tennessee State University
Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
Phone: (423) 439-6053 Fax: (423) 439-6060

IRB APPROVAL – Initial Expedited Review

July 19, 2013

Zhanxin Sha

Re: Kinematics analysis of sprint performance
IRB#: c0313.6s
ORSPA #:

The following items were reviewed and approved by an expedited process:

- xform new protocol submission, CV of PI, Informed consent document version 2/27/2013*

The item(s) with an asterisk(*) above noted changes requested by the expedited reviewers.

On **June 18, 2013**, a final approval was granted for a period not to exceed 12 months and will expire on **June 17, 2014**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (ICD version 2/27/13 stamped approved 6/18/2013)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to

Accredited Since December 2005

eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Brian C. Martin, Ph.D., Vice- Chair
ETSU Campus IRB

cc: Kimitake Sato

APPENDIX B: Informed Consent Document

PRINCIPAL INVESTIGATOR: Zhanxin Sha

TITLE OF Study: Kinematics analysis of sprint performance

Informed Consent Form

Introduction:

This Informed Consent form will explain participation in a research study. It is important that you read this material carefully and then decide if you wish to volunteer.

Purpose:

The purpose of this research is to analyze limb movement at the acceleration and maximum speed phases of sprinting in order to determine what kinematics factors that relate to 60 meter sprint performance. In addition, kinetic factors from isometric mid-thigh pull, vertical and horizontal jumps that related to causes of sprint performance differences between fast and slow sprinters will be determined.

DURATION:

There are 2 testing session involved. All testing will be measured during normal training sessions at two different days; this is to minimize the influence of fatigue-caused performance decrease during each testing event. Thus, there will be at least 36 hours between testing sessions and all the testing will be done at the same time within the practice sessions. Before the first testing session, anthropometric, body composition, and body weight will be measured. For the body composition measurements, 7 skin fold testing measurements will be conducted. An auuto electronic force plate will be used to calculate your body mass. The length of your upper and lower limbs will be measured by ruler (details listed below). All of those measurements will take approximately 15 minutes. Next, reflective markers will be attached to the surface of your joints. (Position of markers listed below). Then, your sprint performance and kinematics data will be recorded and measured. After sprint testing, static and countermovement jumps, vertical depth jump and single leg horizontal depth jump will follow. There will be 2 trials recorded for each type of jump.
The second testing session will include isometric mid-thigh pulls only. After warm up, you will be standing in the standardized position on the force plate. Your hands will be fixed to the bar using weightlifting straps and athletic tape to prevent hand movement and to ensure a maximum effort could be given without the limitation of hand grip strength. Three trials will be recorded for this test.

APPROVED
By the ETSU IRB
JAN 30 2014
By
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
JUN 17 2014
ETSU IRB

PROCEDURES:

1. Anthropometrics: the length of your upper and lower limbs will be measured with tape measure. Distance from wrist to shoulder will be measured on both sides. Distance from ankle to hip bilaterally.
2. Body mass will be measured.
3. Body Composition (The sum of seven skin-folds) will be obtained. The skin fold tests included will be: chest, abdominal, triceps, thigh, shoulder, waist and lower back. Determination of body composition from skin-fold measurement is based on the fact that a large proportion of total body fat is stored directly underneath the skin. Your skin will be grasped by the researcher`s thumb and forefinger about 0.5 inches from the measurement site following the natural fold of your skin. Your skin will be lifted up from the muscle, calipers will be applied, and the researcher will wait for 4 seconds before reading the calipers. The aim of waiting for 4 seconds is to minimize measurement errors by allowing the indicator needle of the calipers to stabilize. There will be no feeling of pain during the measurement.
4. Reflective markers will be attached to your shoulder, upper arm, elbow, lower arm, wrist, hip, knee, ankle, heel, toe for on both the left and right sides. Additional reflective markers will be attached on the chest, sternum, neck, lower back and at right side of scapula.
5. Six cameras will be set around the running field, three cameras on each side, located seven meters from the track. As a participant you will just sprint as normal. As you pass the cameras your movement will be captured.
6. Static vertical jump: during static vertical jump, you will start from knee flexion at 90 degrees with measurement by goniometry, hold that position and as instructor's count 3-2-1 then try to achieve maximum height.
7. Countermovement jump: there is no knee angle control for counter movement jump; you can choose their most comfortable level and try to jump as high as possible.
8. Bilateral double feet vertical depth jump: you will step off from a 40 cm (15.7 inches) height box without stepping down or jumping and then jump as high and as quickly as possible after feet contact force plate.
9. Single leg horizontal depth jump: you will step off from a 20 cm (7.8 inches) height box to the floor without stepping down or jumping. Then, jump as far and as quickly as possible after the foot contacts with ground.
10. Isometric mid-thigh pull: you will stand on the force plates. Bar heights will be set specific to the individual, corresponding to a knee angle of 125°±5° and a hip angle of 175°±5°. Your' hands will be fixed to the bar using weightlifting straps and athletic tape to prevent your hand movement and to ensure a maximum effort could be given without the limitation of hand grip strength.

PRINCIPAL INVESTIGATOR: Zhanxin Sha

TITLE OF Study: Kinematics analysis of sprint performance

ALTERNATIVE PROCEDURES/TREATMENTS:

You can continue to train as you normally do and not take part in this study

POSSIBLE RISKS/DISCOMFORTS:

There is no risk from measurements of body composition, weight and anthropometrics. There is no known risk from placement of reflective markers on the joints of your body, or use of the cameras and motion analysis software.
There is minimal risk when doing vertical jumps and horizontal jumps since those two types of jumps involve impact on muscles when you landing on the ground, the possible risks/discomforts of your involvement include: muscle soreness from exercises, and minimal risk of injury due to strain, or sprains but risk levels will not be greater than normal practice session.
There is minimal risk for doing isometric mid-thigh pull because this type of exercise requires you to pull with 100% of your effort. The possible risks/discomforts of your involvement include: muscle soreness from exercises, and minimal risk of injury due to strain or sprains. However, the risk will not greater than your normal weight lifting sessions such as squat—strength exercise which being used for strength and weight training 3 times per week.

POSSIBLE BENEFITS:

This study uses cameras to observe and collect data during the sprints performed as part of the regular practice sessions. Possibly, results from the study will assist you and your coach to understand the advantages and disadvantages of your techniques from biomechanical analysis perspective. Moreover, with kinetics data from jumps and isometric mid-thigh pull, you will know what needs to be improved to enhance 60 meter sprint performance from physical and conditioning perspectives.

FINANCIAL COSTS:

There are no financial costs to the participants.

COMPENSATION IN THE FORM OF PAYMENTS TO RESEARCH PARTICIPANTS:

There is no compensation for your participation in this research.

VOLUNTARY PARTICIPATION:

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. Your choice will have no impact on your status on the track and field team. You may quit by calling Zhanxin Sha, whose phone number is (620) 757-8318 or Dr. Kimitake Sato, (423) 439-5138.

CONTACT FOR QUESTIONS:

If you have any questions, problems or research-related medical problems at any time, you may call Zhanxin Sha at (620) 757-8318, or Dr. Kimitake Sato at (423) 439-5138. You may call the Chairman of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at(423)-439-6055 or (423)-439-6002.

CONFIDENTIALITY:

Because this study includes measuring and recording your movements during your practice sprints, this means that your teammates, your coach, and the sports scientists will be present.

One of the ways that sports scientists work is to provide information to coaches about their athletes and the athletes' training programs. Information may be helpful to coaches as they work to improve training programs. You may choose whether you want the results of these research tests provided to your coach.

Please indicate your choice below:

☐ Yes, please give my results from this research study to my coach.

☐ No, please do NOT give my results from this research study to my coach.

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in a locked drawer in Dr. Kimitake Sato's office for at least 5 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and the Exercise and Sport Science department will have access to the study records. In addition, if you gave us permission by checking the "yes" box above, your coach will be given the results of the research tests done as part of this study. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

APPROVED
By the ETSU IRB
JAN 30 2014
By ______
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
JUN 17 2014
ETSU IRB

PRINCIPAL INVESTIGATOR: Zhanxin Sha

TITLE OF Study: Kinematics analysis of sprint performance

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been given the chance to ask questions and to discuss your participation with the investigator. You freely and voluntarily choose to be in this research project.

SIGNATURE OF PARTICIPANT DATE

PRINTED NAME OF PARTICIPANT DATE

SIGNATURE OF INVESTIGATOR DATE

SIGNATURE OF WITNESS (if applicable) DATE

APPROVED
By the ETSU IRB
JAN 3 0 2014
By JO
Chair/IRB Coordinator

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VITA

ZHANXIN SHA

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	Track coach, Emporia Track Club, track and field**,** Emporia, KS. 2010.
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Publications:	Sha, Z.X. Sato, K., Stone, M. H. (2014). Correlation of vertical jump performance to D-I male sprinters' acceleration and maximal velocity running performance. (In Press)
	Sha, Z.X., Bailey, C.A., Mclnnis, T. C., Sato, K., Stone, M.H. (2014). Using kinetic isometric mid-thigh pull variables to predict D-I male sprinters' 60m performance**.** Proceedings of 2014 International Society of Biomechanics in Sports. _
	Sha, Z.X. Sato, K. Stone, M. H. (2014). Kinematic analysis magnitude of acceleration for braking and propulsion phases during foot contact phase at maximal speed sprinting. Proceedings of 7th World Congress of Biomechanics.

Lu, C., Ha, T.Z., Wang, X.H., Liu. L., Zhang, X., Kimbrough, E.O., Sha, Z.X., Guan, M.J., Schweitzer, J., Kalbfleisch, J., Williams, D., Li, C.F. (2013). The TLR9 ligand, CpG-ODN, Induces Protection against Cerebral Ischemia/Reperfusion Injury. Journal of American Heart Association (Accepted).

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