The Science of Speed: Determinants of Performance in the 100 m Sprint

Aditi S. Majumdar¹ and Robert A. Robergs²

¹Exercise Science Program, Department of Health, Exercise and Sports Sciences, The University of New Mexico, Albuquerque, NM 87131, USA
E-mail: aditi@unm.edu
²School of Human Movement Studies, Charles Sturt University, Bathurst 2795, NSW, Australia
E-mail: rrobergs@csu.edu.au

ABSTRACT
Performance in the 100 m sprint is influenced by a multitude of factors including starting strategy, stride length, stride frequency, physiological demands, biomechanics, neural influences, muscle composition, anthropometrics, and track and environmental conditions. The sprint start, the accelerative phase of the race, depends greatly on muscular power. Three considerations of the sprint start are reaction time (time to initiate response to the sound of the starting gun), movement time (onset of response until end of movement) and response time. Maximal velocity running is a result of stride length and stride frequency. While stride length can be greatly limited by an individual’s size and joint flexibility, stride frequency can be affected by muscle composition, neuromuscular development, and training. Although 100 m sprint world record times have progressed drastically, there is limited evidence for how technology has contributed to such improvement. As such, human physiology and physique combine to be the most influential determinants of improved sprint performance.

Key words: Acceleration, Biomechanics, History of Track-and-Field Athletics, Reaction Time, Running Velocity, Sprinting

INTRODUCTION
The shortest existing competition in outdoor track and field running events is the 100 m sprint. As in any sprint race, the primary objective of the 100 m sprint is to cover the designated distance in the shortest time possible. Historically, the race has been recognized as a focal component of track and field, as the man and woman who owns the gender-specific world record in the 100 m sprint also traditionally carries the prominent title of “world’s fastest athlete”.

Reviewers: Lee Brown (California State University, Fullerton, USA) Yannis Pitsiladis (University of Glasgow, UK)
As compared to other sprinting events, the relative simplicity of the 100 m sprint makes it ideal for studying the elements of sprint running. Unlike other track-and-field sprints, such as the 200 m or 400 m event, the 100 m sprint does not involve a curve of the track. Thus, running technique involves purely linear movement, and no centrifugal or centripetal (outward and inward radial) forces.

Given recent world record accomplishments in the male 100 m sprint event, we thought that a review of this event, and the multiple determinants to 100 m sprint performance would be a timely addition to the scientific and coaching literature within athletics. Consequently, the purpose of this review is to identify the features of the 100 m sprint that make it such an iconic event, and summarize the multi-faceted determinants to sprint running performance so that understanding and commentary on performance can be based on science rather than speculation or personal bias.

A SHORT HISTORY OF THE 100 m SPRINT

The 100 m sprint first officially appeared in the Modern Olympics in 1896, in Athens, Greece. In the inaugural race, Thomas Burke, of the United States, claimed victory at 12.00 seconds, and was the lone sprinter who followed a squat starting stance.1 During the initial decades of the Olympics, the track used in Olympic and World athletic events was predominantly made of crushed cinder, clay, or dirt. In contrast, today’s tracks are made of synthetic material designed to offer enhanced cushioning and elastic recoil, or at least this is the theory as we explain later in this review.

Since the late 1900’s, the sprint event has remained relatively unchanged, except for the improvements in track conditions and footwear worn by the athletes. Tables 1 and 2 present the top-10 100 m sprint times for males and females, respectively, and reveals that all occurred since 1988. Figures 1a and b presents a chart of the world record times for the 100 m sprint for both men and women, spanning 1912 to the most recent world record. There are certain features of the trend for world record improvement that are interesting. First of all, the improved times do not reveal a smooth trend. There are periods of relative stability in world record performance, spanning as long as 1936 to 1956 for men, and 1935 to 1952 for women. Another period of stability occurred from 1968 to 1988 for men.

The current female world record 100 m sprint time of Florence-Griffith Joyner of the USA in 1988 clearly deviates from the prior world record trend from 1948 to 1984 which was remarkably consistent over this time period. The stark difference between the two slopes of Figure 1a reflect interesting changes in the progression of the 100 m sprint pre- to the post World War II era.

Interestingly, the male world record times for the 100 m sprint revealed consistent improvement pre- and post World War II. Like for the women, the improvement in record times for men slowed down (1983 and 1999), yet then surprisingly improved again, and its greatest rate in the history of the event occurred between 1999 and 2008. The current world record of 9.58 s, belonging to Usain Bolt of Jamaica (set August 16, 2009 at the IAAF World Athletics Championships in Berlin, Germany)1 beat his own previous standing world record of 9.69 s at the 1998 Olympic Games in China, by 0.11 seconds, and demolished other previous world records in the 100 m dash, including the world record of 9.74 seconds set on September 9, 2007 by fellow Jamaican, Asafa Powell (Table 1). Like the current world record for the women, the current male record is a major deviation from the recent trend.
### Table 1. Top 10 Men’s All-Time 100-Meter Sprint Times

| Rank | Time (s) | Athlete       | Country | Date  |
|------|----------|---------------|---------|-------|
| 1    | 9.58     | Usain Bolt    | JAM     | 2009  |
| 2    | 9.69     | Usain Bolt    | JAM     | 2008  |
| 3    | 9.72     | Usain Bolt    | JAM     | 2009  |
|      |          | Asafa Powell  | JAM     | 2009  |
| 4    | 9.74     | Asafa Powell  | JAM     | 2008  |
| 5    | 9.76     | Usain Bolt    | JAM     | 2008  |
| 6    | 9.77     | Asafa Powell  | JAM     | 2007  |
|      |          | Tyson Gay     | USA     | 2008  |
|      |          | Usain Bolt    | JAM     | 2005  |
| 7    | 9.78     | Asafa Powell  | JAM     | 2008  |
| 8    | 9.79     | Maurice Green | USA     | 2008  |
| 9    | 9.80     | Maurice Green | USA     | 2007  |
| 10   | 9.82     | Maurice Green | USA     | 1999  |

### Table 2. Top 10 Women’s All-Time 100-Meter Sprint Times

| Rank | Time (s) | Athlete                | Country | Date  |
|------|----------|------------------------|---------|-------|
| 1    | 10.49    | Florence Griffith-Joyner | USA     | 1988  |
| 2    | 10.61    | Florence Griffith-Joyner | USA     | 1988  |
| 3    | 10.62    | Florence Griffith-Joyner | USA     | 1988  |
|      | 10.64    | Carmelita Jeter        | USA     | 2009  |
| 4    | 10.65    | Marion Jones           | USA     | 1998  |
| 5    | 10.67    | Carmelita Jeter        | USA     | 2009  |
| 6    | 10.70    | Florence Griffith-Joyner | USA     | 1988  |
|      | 10.71    | Marion Jones           | USA     | 1998  |
| 7    | 10.72    | Marion Jones           | USA     | 1998  |
| 8    | 10.73    | Christine Aaron        | FRA     | 1998  |
| 9    | 10.74    | Shelley-Ann Fraser     | JAM     | 2009  |
| 10   | 10.74    | Merlene Ottey          | USA     | 1996  |

### DETERMINANTS TO 100 m SPRINT PERFORMANCE

100 m sprint performance is dependent on multiple factors and we have categorized them based on environmental, mechanical/equipment, biomechanical and psycho-physiological labels. Explanations for all items are provided below.

### TIMING THE 100 m SPRINT

Clearly, today’s use of electronic technology in timing athletic performance is unique to the electronic age, and was not available in the early 20th century athletic events. In fact, coordination of the timing to the starter’s gun became electronically automated in 1912, and current standards are that such electronic integration must not add a delay of more than $1/1000$th (0.001) of a second to total time. Prior to 1912, hand-timing via use of stopwatches was used to determine winning times, and shortly after, chronographs and photoelectric recording technology became compulsory for timing accuracy. In 1965, the International Association of Athletics Federations (IAAF) began accepting automatic electronically timed...
Figure 1. Timelines of 100 m Sprint World Records for a) Females, and b) Males. Regression lines for specific segments show the slopes for the rate of improvement.
records for up to the 400 m event. Automatic timing to the hundredth of a second became mandatory on January 1, 1977.

The start of the race is prompted by an official who follows the standard IAAF mandated three-command start that involves two verbal cues and a final, loud gunshot from a starting pistol. The timing of the race begins at the firing of the starting pistol and concludes as the movement of the athletes across the plane of the finish line is electronically monitored. Some technological limitations of timing systems include sensitivity to light, wind, temperature and pressure. However, the most successful and commonly relied on optical systems oscillate at high frequencies, such that they operate optimally despite fluctuations in environmental conditions.2

ENVIRONMENTAL CONDITIONS
Under adequate race conditions, wind is the only environmental factor that may impact the official, documented result of the race. Generally, in the presence of wind, the competitors will race with the wind at their backs. However, the direction in which the competitors will run is officially determined by race officials at the meet. A wind headed the same direction of the race is known as a tailwind. A tailwind exceeding 2.0 mph is sufficient to eliminate a record breaking time.1

THE SPRINT START
The modern 100 m dash race is held on a straight stretch of the standard 400 m surfaced, oval track. According to the International Association of Athletics Federations (IAAF)1, the governing organization of track and field, a crouch start is mandatory for the 100 m dash and all other sprint races up to and including the 400 m dash.

The traditional starting position for sprint racing was a standing start. However, as early as 1884, athletes were increasingly adopting a crouched position, and the use of divots in the ground to better support the feet soon followed. The use of a starting block was accepted in 1937, and today we refer to the use of a starting block and related starting position as the crouch start.3

Starting blocks assist in overall acceleration during the sprint start, as the feet can exert large backwards forces and create a stretch of the calf muscles that consequentially load the muscles. When starting blocks first became mandatory in all sprint races, little scientific research supported the use of starting blocks. Recently, Salo and Bezodis3 compared the two starting stances, standing and crouched, to determine if starting blocks should remain a mandatory implement of sprint races. Salo and Bezodis3 found that in using a staggered, standing start, the sprinter is able to increase acceleration in the initial phase of the race, compared to the crouch start. In a standing start, the distance between the front and rear foot is naturally long, causing the individual to exert a greater push on the front foot once the rear foot has cleared the ground. Although there is an initial delay in movement, a longer push produces a higher force, and thus, a greater velocity.3,4

In the crouch start, elongated spacing between the front and rear block plates correlate to an increase in the duration of front foot impulse, but also starting velocity. In a study conducted by Henry5, a distance of approximately 26 inches, between the feet in a crouched position, produced greater starting velocity than any other distance. Salo and Bezodis3 determined, however, that the greater horizontal velocity advantage of the standing start was inconsequential to the remainder of the race.

The sprint start is best characterized as the period of time between the moment the sound of the starting gun has been received and the moment both feet have cleared the starting
blocks. According to Harland and Steele⁶, the start can account for approximately 5% of total race time in the 100 m dash.

The sprint start involves near maximal activation and complex, functional movements of an athlete’s gross musculature.⁷ A powerful start is crucial to attaining an optimal standard of performance in a sprint race⁴. Three key contributors to the sprint start are reaction time, movement time, and response time. Minimizing the duration of each of these components can contribute to a faster start time, and ultimately a better sprint performance.⁷

Reaction time is the time it takes to initiate the response to a given stimulus. In the sprint start, the stimulus is the sound of the start gun and reaction time is measured by the first change in force after the gun. Movement time is the onset of the response until the end of the movement.⁸ In the sprint start, movement time is monitored from the end of reaction time, when the force by the rear foot on starting block is 0 Newtons, to when the same foot has completed its first successful strike on the ground. Total response time in the sprint start is the time interval that begins at the onset of the “go” signal and halts at the completion of the movement, the first foot strike. Response time is therefore a resultant of the reaction time and movement time combined.

Both legs are equally important in the overall task of the sprint start, but the movement itself is inherently asymmetrical. While both limbs engage in the reactive movement, the trail leg, or the leg in the rear position, is the first to respond.⁴ It remains controversial which leg the sprinter should adopt as the trail leg (the leg placed in the rear position during a staggered stance), as there has been little consistency in theories. Most often, sprinters are encouraged to select a specific leg based on preference, rather than performance.⁸

In the human body, each limb is controlled by the opposite cerebral hemisphere. Because of this unique relationship between each limb and its contralateral hemisphere, Eikenbery et al.⁸ hypothesized that a particular limb may have special access to the specific capabilities of the corresponding cerebral hemisphere, with potential to gateway neurological advantages to improve overall sprint performance. While the right hemisphere has been identified for its role in spatial and attention processing, such as the detection of a signal⁹, the left hemisphere has been identified for its specialization in the execution of muscle forces. The study demonstrated a left-footed start to be consistent with a reaction time advantage, and a right-footed start to be consistent with movement time advantage. A left-foot rear reaction time advantage (26 ms) compared to a right foot rear movement time advantage (104 ms), gave an overall response time advantage of nearly 80 ms. This result was obtained despite varying rear foot preferences among subjects, confirming that asymmetries in the sprint start, a complex, gross motor movement, are due to cerebral organization rather than preferred or practiced stance. In considering the typical sub-10 second outcome of the modern, elite level 100 m dash, a 80 ms advantage can be truly influential in the outcome of the race, suggesting that sprint coaches should emphasize a right foot rear stance in the sprint start.

In regulation with the IAAF¹, the starter verbally initiates the track-and-field sprint start with an “on your marks” command. This command cues the sprinters to assume a crouched position in the starting blocks, such that both feet are in contact with the blocks, hands are placed on the ground behind the starting line, and the knee in rear is relaxed against the surface of the track.

Mero et al.⁴ found sprinters to have greatest velocities out of starting blocks with block angles for both feet set at 40°. Presumably, a 40° block angle offers desirable muscle-tendon lengthening of the gastrocnemius and soleus muscles. Longer initial muscle tendon lengths contribute to greater peak ankle joint moment and power. Decreasing front block obliquity, such that the block angles of 65° and greater demonstrated significantly slower starting
velocities and are not recommended. Decreasing front block obliquity (more of a vertical angle) induces neural and mechanical modifications due to stretch of both muscle and tendons of the gastrocnemius and soleus. Such stretch induces elastic recoil that further supports the velocity of muscle contraction during the explosive pushing phase.

The starter next initiates a “set” command, cuing the athlete to prepare to sprint. The idea is to shift the body center of mass, such that it is forward and upward. Hips will be high, the rear knee will be lifted off the ground, and shoulders will be over the starting line. The athlete will remain in this position until he hears the starting gun fire.

The set position is potentially the most critical position of the sprint start, as optimal body position will translate towards a more consistent, and explosive start. In the set position, the angles of the joints are key towards producing an accelerative position. An angle of 90° between the upper and low parts of the front leg is desirable. Initial velocity is increased with a reduction of the front block angle, as this consequently changes the angles of the knee and ankle, producing a favorable muscle length of the calf that is more powerful. An angle of approximately 120°, between the upper and lower part of the rear leg is desirable, as well. The greater angle allows the rear leg to have a stronger push off the block. The intention is for the rear foot to effectively rotate under the body, to produce a dynamic first step.

Some coaches believe that while the athlete is in the set position, they should actively press hard against the blocks while waiting for the “go” signal. The pressing motion of the feet against the blocks pre-tenses the extensor muscles of the legs. It is expected that in pre-tensing the muscles, the athlete will have an increased ability to generate force in the accelerative phase of the race. However, in a study conducted by Gutierrez-Davila et al., no significant sprint performance differences were observed of muscle pre-tensing in the starting blocks compared with relaxed, or more moderately activated muscles in the starting blocks. On the contrary, Mero and Komi found the sprint start to be enhanced with activation of the important muscles used in sprint acceleration prior to force development on the starting blocks.

The “go” signal is the sound of a gunshot from the starting gun, fired by the starter. The movement triggered by the “go” signal should be explosive and dynamic. The starter is always positioned closest to lane 1. Research has indicated differences in reaction time of athletes at the starting line, based on the distance between the starting gun and the athlete. Those competitors who are assigned to lanes closest to the starter, have the advantage of hearing the loudest “go” signal, and therefore, will have a faster reaction than the rest of the field. Loud auditory stimuli have the potential to significantly increase peak force prior to the maximal execution of a simple task. Adopting this theory, it seems probable that the same concept may apply to a complex task, such as sprinting, and increased peak force at the start would facilitate greater horizontal velocity. According to Brown et al., in an analysis of the 2004 Olympic Games track sprint events, competitors in the inner lanes, the lanes closest to the starter, had significantly lower reaction times than the competitors in the outer lanes. In a study analyzing the sprint start at varying auditory “go” signals, the same researchers discovered the louder the stimulus the shorter the reaction time, and the shorter the time necessary to attain maximal horizontal velocity from the starting blocks. The intensity of the auditory stimulus did not affect the magnitude of maximal horizontal force. However, although Brown et al. were able to provide evidence to suggest modifications be made to current starting procedures, no current accepted alternatives exist to combat the problem.

A false start occurs when the athlete initiates movement prematurely, and not in response to the starting gun. In recent years, engineers have experimented with technologically advanced starting blocks that contain movement detection devices sensitive to forces on the
blocks, to help identify false starts. However, the majority of force plates have been more unreliable, as they are hypersensitive to movement changes. Therefore, false starts are visually monitored by officials at the starting line.\footnote{11}

**ACCELERATION PHASE**
The sprint start is purely accelerative, in that the greatest acceleration during the 100 meter dash is achieved during the first 15 m of the race. The sprint start is relatively unconstrained in both spatial and temporal dimensions.\footnote{8} The only constraining objective is that the athlete accelerates from the starting blocks in a relatively straightforward direction in as little time as possible. The movement triggered by the start gun should be explosive and dynamic. Although high propulsive forces may be desirable for forward acceleration, in order to achieve optimal stride frequencies, vertical emphasis should be minimized. Faster individuals typically exhibit longer ground contact time.

In the event that the first step is too long, the hips will lead the movement, compromising the drive phase inherent to effective acceleration.\footnote{12} From a mechanical perspective, it is important to orient the body so that the mean location of the body mass (body’s center of mass) and the center of gravity is as forward as possible to allow continued forward acceleration.

**MAXIMAL RUNNING VELOCITY**
During sprint running there are two parameters that affect running velocity: stride length and stride frequency. Speed training should therefore target the improvement of these two components, keeping in mind not to compromise biomechanical efficiency (energy input required to run at a certain velocity). An individual’s body mass and body height greatly influence both stride length and stride frequency, independent of the athlete’s physical fitness level.\footnote{13} Muscle mass is important to the accelerative phase of the race, where it is essential to overcome inertia and increase the length of the stride.\footnote{7} Body height has a greater impact on maintaining speed and stride length. Faster men are, in general, taller than slower men.\footnote{14}

An extensive study conducted by Paruzel-Dyja et al.\footnote{14} on a large number of elite 100 m dash sprinters, found stride length, not stride frequency, to have the most dominant impact on success in the 100 m dash for the male gender. Interestingly, the opposite was true for top female sprinters, whose excellence in sprint performance was based on high stride frequency rather than long strides. This analysis suggests a distinction for gender-specific technical training, as different parameters of the 100 m dash are characteristic to each gender.

According to Swanson and Caldwell\footnote{15}, high intensity incline treadmill training is a useful method to trigger adaptations in stride frequency by amplifying lower extremity muscle activation and joint power. However, some researchers argue that high-speed incline treadmill training may not translate to ground-based sprint performance, because total body kinematics differ in the two activities. Other research finds ground-based resistive techniques to decrease both stride frequency and length.\footnote{16}

While muscle power from the lower body is an important determinant of optimal sprint performance, Chelly and Denis\footnote{17} found leg stiffness to significantly correlate with maximal velocity running. Muscle power is a greater contributor during the accelerative phase of the race, while muscular resilience, the efficiency of the muscles to rebound, is inherent to top speed running. The estimated theoretical limit of power output of an Olympic level sprinter is approximately 4400 W. When considering the typical individual who has a body mass of 70 kg, the relative power output is approximately 60 W per kg of body weight. This value is massive, explaining the property of great anaerobic capacity in world-class sprinters.
The two fitted curves are for Usain Bolt (solid line) and Carl Lewis (dashed line) representing the fastest and slowest times of the data set. The in-set graph reveals the differences and similarities in the decrement in running velocity (fatigue) over the final 40 m. The numbers next to the athletes name initials are slopes (m/s⋅s⁻¹).

At the elite level, there still exists a great variance of sprinting methods. Figure 2 illustrates the progression of four world-class sprint athletes through their individual, world-record setting 100 m dash races. Despite differing running techniques and physiques, Carl Lewis (1988), Maurice Greene (1999), Asafa Powell (2005) and Usain Bolt (2008) all display a very similar velocity curves in the 100 m sprint. Usain Bolt remains unique in his greater rate of acceleration (increased velocity over time) and peak velocity (Figures 2 and 3). All athletes began to slow down between the 60 – 70 m distances of the race.
Metabolic factors are important determinants of sprint performance and maximal anaerobic performance. It is believed that genetic factors contribute to about 50% of the variance in short-term anaerobic performance phenotype, although it remains unclear the actual influence of environmental development and genetic factors to differences that are observed in the phenotype.

The 100 m dash is a predominantly anaerobic race, meaning physiologically, mitochondrial respiration (involving the consumption of oxygen) has a minimal contribution to the energy generated. The term ‘anaerobic power’ describes the maximal adenosine triphosphate (ATP) turnover rate by the body, during a short, maximal exercise. As there is always at least a basal rate of oxygen consumption, no exercise performed by the body is totally anaerobic. Nevertheless, the shorter the event, the smaller the ‘aerobic’ contribution.

The 100 m dash is a predominantly anaerobic race, meaning physiologically, mitochondrial respiration (involving the consumption of oxygen) has a minimal contribution to the energy generated. The term ‘anaerobic power’ describes the maximal adenosine triphosphate (ATP) turnover rate by the body, during a short, maximal exercise. As there is always at least a basal rate of oxygen consumption, no exercise performed by the body is totally anaerobic. Nevertheless, the shorter the event, the smaller the ‘aerobic’ contribution.

We know from research of intense exercise for 30 s, that there is about a 30% contribution to ATP turnover from mitochondrial respiration. For the 10 s 100 m sprint, this contribution is probably less than 5%.
The dominant metabolic energy system is the phosphagen system that relies heavily on the muscle store of creatine phosphate (PCr). In the phosphagen system, creatine kinase breaks down creatine phosphate into a creatine molecule and transfers inorganic phosphate (Pi) from PCr to ADP to form ATP. Thus, while the phosphagen system is at work (as long as creatine phosphate remains available) ATP is regenerated at a very high rate and muscle ATP is maintained at a moderately constant level. Interestingly, the phosphagen system can only meet the energy demands of intensely contracting muscle for up to approximately 10 seconds, the time frame encompassing elite 100 m sprint performances.20

While the phosphagen system can efficiently meet energy demands for maximally contracting muscle in an instantaneous manner, its contributions are balanced by the rapid stimulation of the glycolytic metabolic pathway. Glycolytic metabolism, which functions fundamentally on glucose as a fuel source, is an added contributor to ATP turnover during explosive muscle action such as sprint running. Glycolytic metabolism can account for greater than 55% of the energy production during a sprint exercise lasting approximately 10 seconds.21 Like the phosphagen system, the glycolytic system’s capacity is dependent on its specific fuel reserves (mostly muscle glycogen, with a small supply from blood glucose).

Research has demonstrated sprint training to be effective in enhancing the enzyme activity of creatine kinase (catalysis of PCr) and myokinase (also known as adenylate kinase) (resynthesis of ATP from ADP) in the phosphagen system. According to Hirvonen et al., maximal sprint performance depends on an individual’s ability to catalyze high-energy phosphates, as elite sprinters have an augmented ability to breakdown CrP. In a study assessing maximal sprint performances at 40, 60, 80 and 100 m distances, Hirvonen et al.22 established that a decrease in running speed occurs when the body is near depleted of PCr and must rely predominantly on glycolytic metabolism for energy.

Similarly, a higher rate of glycolytic enzymatic activity has been observed in response to sprint training, including enzymes phosphofructokinase, lactate dehydrogenase, pyruvate kinase and glycogen phosphorylase. Most interesting would be the increased expression of lactate dehydrogenase, the enzyme responsible for catalyzing the conversion of pyruvate to lactate, as it solidifies the necessity of lactate conversion. Lactate, commonly thought to hamper performance with accumulation in the body, is actually beneficial to muscle metabolism during sprint running. Lactate production helps offset the effects of metabolic acidosis by buffering, not producing, a proton. In addition, lactate production is an effective and fast mechanism for muscle to regenerate cytosolic NAD+, which is essential for glycolysis to continue and regenerate ATP.23

NEUROMUSCULAR EFFECTS

During sprint running, the entire body engages in movement. Efficient interactions between agonist, antagonist, and synergist muscles in joint kinematics are key characteristics to optimal sprint performance. The agonist muscle, the active muscle, must have the ability to effectively generate great force. At the same time, to get the greatest output from the agonist muscle, the antagonist muscle must relax. In running motion, when one knee extends, the other knee flexes. During knee extension, the agonist muscle group is the quadriceps (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius) and the antagonist group is the hamstring muscles.

According Daley et al.24, all terrestrial animals adhere to a common joint kinematics during steady movement, despite natural variability, including number of legs, size and shape of legs, and body mass. Sprint running is characteristically a complex and multi-joint exercise. Improved movement coordination will have a greater impact on muscle force gains
in more complex, multi-joint exercises. Although the lower body receives considerably more attention in sprint running research, the upper body has an important role of counterbalancing the actions of the lower body. The shoulder region is the origin of the arm swing, while the hip region is the origin of the leg swing. The arms act contralaterally to each leg, which is inherent to running. Stride frequency, which is an important contributor to maximum speed running, will be best accommodated by strong shoulders and hips, as they will be essential to generating a faster swing.

During maximal sprinting, it is both biomechanically and aerodynamically favorable for a sprinter to have a slight forward lean in the body. A forward lean of the body optimizes the striking angle of the foot. The athlete is better positioned to strike on the forefoot during ground contact, a region of the foot that is commonly termed the ball of the foot. A forefoot strike can more easily translate to a quicker toe-off in initiation of the next stride, than an alternative foot strike. A flat-footed strike or a heel-to-toe strike, would both be detrimental to purpose of a sprint stride, which is to generate a fast and explosive turnover for a faster time. Heel contact with the ground would prolong the stride initiation phase.

To improve speed, muscles and movements inherent to sprinting action should be specifically targeted. Research demonstrates that exercises that emphasize the speed and full range of movement have a greater effect on sprint performance than exercises that emphasize only absolute strength. Sprint running, like most athletic activities, requires strength at fast velocities (power). Studies demonstrate strength increases to be specific to the velocity at which they are trained. Thus, it is optimal to target both force production and velocity of muscles in resistance training to maximize power performance, which cannot be achieved by traditional heavy resistance strength training that follows a high force and low velocity format. To increase power and sprint performance, resistance training must be conducted at high speed.

Every gross and fine motor movement impacts the nervous system in a positive or negative manner, thus it is important to train neural pathways to behave accurately with the desired movement pattern. With increased complexity of movement, the greater the number pathways trafficking in the brain and neuromuscular system. In sprint training, the nervous system must be stimulated to act specifically to fast movement. Cardiovascular fitness is an important component of high-speed performance sports, but training involving slow movements will counteract the goal of sprint performance, which is to be dynamic and explosive. Nevertheless, the only condition where this may not apply is for the use of resistance training with high loads for the development of increased muscular strength.

**MUSCLE COMPOSITION**

Human variations in skeletal muscle properties affect maximum speed potentials. For example, individuals who have a genetic expression of fast-twitch muscle will be better suited to events that involve rapid and forceful muscle contractions such as sprinting. Researchers believe that muscle fiber composition is genetically determined and minimally affected by training. Type I, oxidative muscle fibers, are rich in mitochondria, red in appearance and carry great endurance capacity. Type II muscles fibers, also known as fast-twitch muscle fibers, possess few mitochondria, are white in appearance, and have a high capacity to contract forcefully and rapidly, due to having different structures of key proteins involved in muscle contraction that allow faster ATP breakdown and contractile protein movement during contraction. Fast-twitch fibers are commonly additionally classified as fast-twitch type a (IIa), (moderate fatigue resistance) and fast-twitch type b/x (IIb/x) (low
fatigue resistance). While training does not affect the distribution and amount of slow-twitch and fast-twitch muscle fibers, type IIa and type IIb/x fiber types may interconvert with training.27

Muscle fiber size is greatly affected by age and training. Muscle fiber area increases by 15-20 fold (hypertrophy) from birth through young adulthood. While increases in muscular strength are often accompanied by muscle hypertrophy, an increased ability to generate force does not always occur with simultaneous increases in muscle cross-sectional area.25 This phenomenon is a result of an improvement in the capacity of the neuromuscular system to recruit and activate a greater number of muscle motor units.

TECHNOLOGY
The introduction of technology to the sport of track and field makes it difficult to ascertain whether the decline in men’s 100 m dash world record times should be attributed to more technology, raw physical ability of the athlete, knowledge of proper technique, or other variables. However, it is clear that world records have significantly changed over the decades (Figure 1), and while female world-record times have not improved since 1988, the recent trend for continued improvement in male sprint world-record times raises the possibility for equipment-centered technological contributions to sprint performance.

Since the 18th Olympiad held in Japan, the last venue to host an Olympics with a track made of cinders, all running and approach surfaces have been made with synthetic materials. Percy Beard pioneered the first synthetic hard surface track in the 1940s. Since then, synthetic track surfaces have dramatically advanced to provide greater recoil for improved running times. The first spiked shoes were used in 1868 in a track meet hosted in London, and according to historians the shoes were helpful in winning a prize in every event in which they were used. Stefanyshyn and Fusco28 determined that increasing shoe stiffness increases sprint performance by modifying tension in the calf muscles.

Research surrounding synthetic tracks has been contradictory. According to Stafilidis and Arampatzis,29 although changes in track stiffness may cause differences in joint displacement, the center of mass movement, ground contact times and lower limb mechanics remain unaffected. Whereas in the study by McMahon and Greene,30 very compliant surfaces contributed to an increase in ground contact time and decreases in step length, leading to slower running speeds.

Despite advances in technology, modern-day sprinters have limited control over technology. Essentially, each competitor has equal access to racing technology. Therefore, the recent acute differentiations between sprint times, may suggest that human ability is a much greater contributor to sprint performance in the modern-day 100 m sprint than technology itself.

CONCLUSION
Adaptations in sprint performance are gauged through improvements in sprint times. Training modality and intensity will dictate the body’s neurological and muscular adaptations. Although not discussed in this article, sprint performance greatly depends on the health and motivation of the athlete. Injuries can considerably hamper performance, as can poor mental focus. It is also important to recognize frequent ergogenic aid and supplement use amongst athletes for performance enhancement. While such conduct is not encouraged or accepted by the greater athletics community, supplementation may be as much a factor in modern sprint performances as training programs that enhance technique.

When considering whether sprinting speed can be improved through training,
constructive proof lies in the fact that personal records are constantly being broken by individuals. In the year of 2008, Usain Bolt posted a total of ten sub-10-second 100 m dash times, all career best times and none associated with drug abuse.

Optimal sprint performance depends on many controllable and non-controllable factors. Aspects that are fixed are an athlete’s anthropometric measurements (height, body cross-sectional area, limb lengths) and to a large extent muscle composition. To combat these limitations, sprint coaches seek training programs that augment an athlete’s strength, power, and neuromuscular system, for an overall positive effect on sprint performance. As described in this article, sprint training programs must aim towards increasing the recruitment and activation of an athlete’s gross musculature, such that elements characteristic of top short-sprint performance come naturally for the athlete. These key attributes include an explosive start, a smooth transition to maximal running speed without compromise in the accelerative phase and maintenance of top speed throughout the remainder of the race. Sport-specific training and resistance training at high velocities will gateway the greatest adaptations in musculature and kinematic control.

REFERENCES
1. International Association of Athletics Federations, The Official Athletics Website, Retrieved February 18, 2009, from http://www.iaaf.org
2. Wagner, G., The 100-Meter Dash: Theory and Experiment, The Physics Teacher, 1998, 36, 144-146.
3. Salo, A. and Bezodis, I., Which Starting Style is Faster in Sprint Running – Standing or Crouch Start?, Sports Biomechanics, 2004, 3(1), 43-54.
4. Mero, A., Kuutinen, S., Harland, M., Kyrolainen, H. and Komi, P.V., Effects of Muscle-Tendon Length and Joint Moment and Power During Sprint Starts, Journal of Sports Sciences, 2006, 24(20), 165-174.
5. Henry, F.M., Force-Time Characteristics of the Sprint Start, Research Quarterly, 1952, 23(3), 301-317.
6. Harland, M.J. and Steele, J.R., Biomechanics of the Sprint Start, Sports Medicine, 1997, 23(1), 11-20.
7. Brown, A.M., Kenwell, Z.R., Maraj, B.K.V. and Collins, D.F., “Go” Signal Intensity Influences the Sprint Start, Medicine and Science in Sports and Exercise, 2008, 40(6), 1142-1148.
8. Eikenberry, A., McLaughlin, J., Welsh, T.N., Zerpa, C., McPherson, M. and Newhouse, I., Starting with the “Right” Foot Minimizes Sprint Start Time, Acta Psychologica, 2008, 127, 495-500.
9. Mieschke, P.E., Elliot, D., Helsen, W.F., Carson, R.G. and Coull, J.A., Manual Asymmetries in the Preparation and Control of Goal Directed Movements, Brain and Cognition, 2001, 45(1), 129-140.
10. Gutierrez-Davila, M., Dapena, J. and Campos, J., The Effect of Muscular Pre-Tensing on the Sprint Start, Journal of Applied Biomechanics, 2006, 22, 194-201.
11. Cronin, J.B., Green, J.P., Levin, G.T., Brughelli, M.E. and Frost, D.M., Effect of Starting Stance on Initial Sprint Performance, Journal of Strength and Conditioning Research, 2007, 21(3), 990-992.
12. Segers, V., Aerts, P., Lenoir, M. and Clerq, D.D., Dynamics of the Body Centre of Mass During Actual Acceleration Across Transition Speed, The Journal of Experimental Biology, 2007, 210, 578-585.
13. Geyer, H., Seyfarth, A. and Blickhan, R., Compliant Leg Behavior Explains Basic Dynamics of Walking and Running, Proceedings of the Royal Society B, 2006, 273, 2861-2867.
14. Paruzel-Dyja, M., Walaszczyk, A. and Iskra, J., Elite Male and Female Sprinters’ Body Build, Stride Length and Stride Frequency, Studies in Physical Culture and Tourism, 2006, 13(1), 33-37.
15. Swanson, S.C. and Caldwell, G.E., An Integrated Biomechanical Analysis of High Speed Incline and Level Treadmill Running, Medicine and Science in Sports and Exercise, 2000, 32(6), 1146-1155.
16. Myer, G.D., Ford, K.R., Brent, J.L., Divine, J.G. and Hewett, T.E., Predictors of Sprint Start Speed: The Effects of Resistive Ground-Based vs. Inclined Treadmill Training, Journal of Strength and Conditioning Research, 2007, 21(3), 831-836.
17. Chelly, S.M. and Denis, C., Leg Power and Hopping Stiffness: Relationship with Sprint Running Performance, *Medicine and Science in Sports and Exercise*, 2001, 33(2), 326-333.

18. Van Praagh, E. and Dore, E., Short-Term Muscle Power During Growth and Maturation, *Sports Medicine*, 2002, 32(11), 701-728.

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

20. Cheetham, M.E., Boobis, L.H., Brooks, S. and Williams, C., Human Muscle Metabolism During Sprint Running. *Journal of Applied Physiology*, 1986, 61(1), 54-60.

21. Hautier, C.A., Wouassi, D. and Arsac, L.M., Relationships Between Postcompetition Blood Lactate Concentration and Average Running Velocity Over 100m and 200m Races, *European Journal of Applied Physiology*, 1994, 68, 508-513.

22. Hirvonen, J., Rehunen, S. and Rusko, H., Breakdown of High-Energy Phosphate Compounds and Lactate Accumulation During Short Supramaximal Exercise, *European Journal of Applied Physiology*, 1987, 56, 253-259.

23. Robergs, R.A., Ghiasvand, F. and Parker, D., Biochemistry of Exercise-Induced Metabolic Acidosis, *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 2004, 287, R502-R516.

24. Daley, M.A., Felix, G. and Biewener, A.A., Running Stability is Enhanced by a Proximo-Distal Gradient in Joint Neuromechanical Control, *The Journal of Experimental Biology*, 2007, 210, 383-394.

25. Ross, A., Leveritt, M. and Rick, S., Neural Influences on Sprint Running: Training Adaptations and Acute Response, *Sports Medicine*, 2001, 31(6), 409-425.

26. Costill, D.L., Daniels, J., Evans, W., Fink, W., Krahenbuhl, G. and Saltin, B., Skeletal Muscle Enzymes and Fiber Composition in Male and Female Track Athletes, *Journal of Applied Physiology*, 1976, 40, 149-54.

27. Prampero, P.E., Fusi, S., Sepulcri, L., Morin, J.B. and Antonutto, G., Sprint Running: A New Energetic Approach, *The Journal of Experimental Biology*, 2005, 208, 2809-2816.

28. Stefanyshyn, D. and Fusco, C., Increased Shoe Bending Stiffness Increases Sprint Performance, *Sport Biomechanics*, 2004, 3(1), 55-66.

29. Stafilidis, S. and Arampatzis, A., Track Compliance Does Not Affect Sprinting Performance, *Journal of Sports Science*, 2007, 25(13), 1479-1490.

30. McMahon, T. and Greene, P., The Influence of Track Compliance on Running, *Journal of Biomechanics*, 1979, 12, 893-904.