Sprinting: A Biomechanical Approach By Tom Tellez

World class male sprinters stride approximately forty-three times for a 100 meter race. If a mechanical error costs one-one thousandth of a second per stride, the total cost is .043 seconds by the finish. How can one be an efficient sprinter? However daunting the question appears, an answer lies in scientific principles alone. Kinesiology, biomechanics, and the laws of physics govern every sprinter's technique. Kinesiology, the study of movement, dictates how a sprinter should move. Contributing to the study of movement is the discipline biomechanics, which refers to the engineering of the body and laws of physics governing it. While referencing laws of physics, kinesiology and biomechanics view the body as a unified system of interdependent parts, an approach necessary for proper analysis.

Overview

At the start of a race, the body must begin movement from a rest state. Once moving, the body requires time to build into full speed, or accelerate to full speed. At the beginning of this process, stride length as well as the number of strides per unit of time is small. However, both increase as acceleration increases. While having the ability to accelerate over 100 meters would be ideal, the body is only capable of accelerating for approximately sixty meters. The last forty meters would simply be maintaining technique and speed. Analysis of sprint mechanic s explains the finer nuances of sprint technique, including impulse, stride length, stride frequency, running velocity, arm movement, and leg action.

Impulse

Impulse is not only a term for the foot-ground contact created by each step but also a numeric value defined as force X time. This is the starting point to understanding scientific sprint technique because the impulse is the body's only interaction with the ground, the one and only interaction, which produces linear movement. Impulse ultimately defines how the body should perform rotary movement (movement of body levers relative to body). Vector calculus defines impulse: each impulse has a direction and magnitude.

Direction is the mixture of horizontal and vertical components, while magnitude is the measure of force. The best sprint technique consists of an ideal ratio between downward push and horizontal push (Fig. 9). This ratio, however, changes throughout the sprint race. Concerning force, of course great force can yield great stride length. However, misapplication of force translates to poor technique and loss of momentum. While the horizontal and vertical components of force within impulse play a role in creating body position, body position is also rotary. The ideal body position is perpendicular to the ground, where neck and head fall naturally in line. Depending on the impulse, the body may lean from the ground, as in the drive phase of sprinting, or remain vertical.

One finer detail of impulse relates to how various athletes contact the ground. 100-200 meter sprinters contact the ground on the ball of the foot (Fig. 1), 400-800 meter runners' contact in the arch (Fig. 2) and 1500 meter runners and up use almost the entire foot as a contact point (Fig 3).

While producing the numerical value of each step in a print race requires special technologies, coaches can judge the quality of impulse by measuring momentum. For example, when sprinters show a "low and long" look like that of an ice skater, one possible error is too much horizontal force. A dramatic example of too much downward force would be an athlete who simply jogs in place without moving. But what if two athletes within a race produce near-perfect directional ratios, which one wins?

The one applying more force, within the least amount of time wins (Weyand et al.1998). Force applied for long time intervals requires more energy output than force application for shorter time intervals. It is force applied with the proper directional ratio, which increases stride speed and creates longer stride length.

Stride Length

Stride length is the distance the center of gravity travels between each foot contact. Stride length is the resultant of momentum plus net impulse, which is given to the mass. It can be examined as the following: takeoff distance, flight distance, and landing distance (Fig. 4)

Takeoff Distance

Takeoff distance is the distance the center of gravity travels between the landing point and the point where ground contact is broken. The velocity at which the center of gravity is projected forward is also critical to the flight phase of the stride and is determined by the velocity at touch down and the vertical and horizontal impulses. Thus the speed through the takeoff distance along with good body position and angle of projection determines the takeoff velocity. It will therefore be advantageous to have a big takeoff distance coupled with a great amount of angular speed as the time element of impulse diminishes. Here, it should be noted that the negative velocity of the foot sets up the body position for take off but contributes very little to the actual take off which is the result of pushing the ground away from the body (body away from the ground).

Flight Distance

The flight distance is the distance that the center of gravity travels in the non-support phase of the stride. These factors determine the flight distance: angle of impulse, velocity at takeoff, relative height of center of gravity at takeoff, air resistance, and acceleration due to gravity.

Landing Distance

The landing distance is the distance the center of gravity is away from the landing foot. This distance is relatively short so as to reduce the breaking forces, which decelerate the body. The point of course is to put the food down in a place, which can mechanically develop the most power. The foot lands slightly in front of the center of gravity before moving directly under the center of gravity for push off. If the foot lands behind the center of gravity, stumbling results. Whereas if the foot is too far forward I a reaching step, contact time with the ground will be too long, requiring too much force, resulting in a loss of momentum by the time the body is in a position to push off of the ground effectively.

Stride Frequency

Stride Frequency is the number of strides taken per unit of time. Stride time is easily confused with stride frequency. Stride time is the time it takes to complete one stride (time of support and time of nonsupport). Stride speed and angular velocity through the full range of motion (front and back oscillation) determine stride time. Because stride speed depends on the body state (fitness), it is more of a physiological function (muscle type, muscle flexibility, strength, neuro-muscular coordination, etc.) than biomechanical function. But, the paths the legs take that create speed and mechanical advantage is biomechanical.

Running Velocity

Running velocity is a product of stride length times frequency. Each athlete has a unique combination of the two at different running speeds. Common analysis of stride length and frequency mistakenly show the two inversely related. Stride length frequency are interdependent, where the relationship is based on the amount of resistance that must be overcome. Power (force X velocity) generated by the muscles improves stride length and frequency. The velocity component of power allows more work to be done (stride length) and increases stride speed (stride frequency).

ARMS

Coordinated movement of arms and legs remains the key to efficient sprinting. It is through range and force that the two coordinate. While the movement coordinates, arms lead legs in tempo and range. The following method of movement produces the proper range and force necessitated by the legs.

The hand is positioned approximately shoulder-high, but not exceeding the chin, and slightly in front of the chest (Fig. 8). From this point, the hand initiates the downward stroke by flipping downward while the upper arm rotates backwards from the shoulder, and the elbow joint opens or increases the angle between forearm and upper arm (Fig. 7). After the hand passes by the hip, the elbow joint begins to close again and drives backwards and upwards while the shoulder continues rotating through full range of motion (Fig. 6).

The swing forward requires a reversal of this process, where the elbow opens again while passing by the hip but closes after passing the hip until he hand achieves the approximate-shoulder-high position. Forearms and chest remain as relaxed as possible.

Scientifically speaking, the shoulder is the axis of rotation for the arm, while the elbow acts to shorten the lever when necessary. Closing the angle reduces the moment of arm inertia, increasing angular velocity, in turn creating quicker turnover. Arm movement without utilizing the elbow joint produces a straight-arm, pendular-like swing moving much too slow for leg coordination. Arm swing can allow for greater takeoff distance, enhancing stride length.

Leg Action

Overview
The vertical force comes at take-off when the mass is elevated by pushing downward (pushing off the heel back onto the ball of the foot). The recovery foot steps up and over the drive knee as the foot takes the shortest path to the front of the body as the center of mass rises above the surface (Fig. 7 & 8). The knee then raises and extends as the foot moves forward and the shin becomes plumb (Fig. 7). The thigh drops towards the ground while the knee extends, causing the foot to have a negative velocity at foot placement. As the athlete builds momentum (mass X velocity) the ratio between both forces (vertical and horizontal) increases as the net horizontal force decreases. The stride becomes progressively quicker and longer as stride frequency and length are optimized.

Stretch Reflex
The stretch reflex acts similarly to loading a "Y" sling shot, or forked sling shot. Before shooting the projectile, it remains poised in the stretched elastic, just as the hip flexors remain stretched before the recovery phase. When the sling shot elastic is released, it pops back into original form, sending away the projectile. Novacheck along with Vaughan claim that sprint efficiency is due in part to "the storage and later return of elastic potential energy by the stretch of elastic structures (especially tendons)" (Novacheck 81). Furthermore, stretched tendons efficiently return energy upon recoil (Novacheck 84). The stretch reflex refers mainly to the knee cycling during the recovery phase.

Knee Action
The sling shot release parallels the leg recovery phase: the knee cycles through because the hip flexor pops back into normal position from its stretched position. Therefore, the knee coming through occurs naturally and does not necessitate an athlete's conscious effort. Furthermore consciously lifting the knee high while sprinting inhibits the legs natural timing during the recovery phase. Consciously creating a high knee lift or normal knee lift is like stretching back a sling shot with projectile and helping push the projectile with the hand while the elastic is releasing. The action would cause a reduction of elastic force, resulting in slower movement with the sling shot as well as with sprinting.

Scientific Overview

Start

At the start, mass is at rest. The property of inertia inherent in the mass resists changes in velocity (a vector with magnitude and direction) and according to Newton's first law will maintain this velocity unless acted on by an external force. The amount of inertia within the mass is proportional to the amount of mass; objects with more mass require more force to move initially. When the sprinter applies force to the blocks, inertia is overcome and linear movement begins.

Stride length and frequency are low because of inertia. This is why the first stride is the slowest and shortest. Force is initially applied backward and downward where the shin angles somewhat close to the ground and behind the knee. This motion is piston-like as it pushes the mass forward from its rest state. Horizontal impulse is greatest at this point (Weyand et al. 1991) but diminishes as mass increases speed. It is the net force that causes the mass to accelerate: the difference in mass forward force and the pushing force. At the start of a run when resistance is at its highest, it is easier to increase stride length because force needs something to work against.

Acceleration

Shortly after starting, stride length and frequency increase. As momentum builds, stride length tends to stabilize as momentum builds, resistance diminishes and net force approaches zero. Concurrently, frequency increases because resistance constantly decreases.

In short sprints, it is important to accelerate over the longest possible distance in the shortest amount of time and try to maintain and decelerate gracefully. After the athlete has been successful in setting the body in motion, and the center of mass begins to gain momentum, a toppling would occur if the feet continued to go backward and downward. The acceleration process then goes through a mechanical transition where the legs go through the form of cycling motion. The lever lengthens to give a mechanical advantage and shortens on the recovery phase to give a speed advantage. The position of the body dictates how reactive forces affect the center of mass.

The center of mass accelerates at a decreasing rate until maximum velocity (top speed) is attained. At max speed, the net horizontal force applied is zero. The ground tends to recede faster when the body picks up speed, resulting in reduction of contact time as well as effective force because of reduction in resistance. At this point in the race, the athlete tries to keep the effective force at zero until the net horizontal force becomes negative. When body momentum becomes greater than that of the legs, the body starts toppling over, causing a braking action each time the foot hits the ground. At this point, the athlete tries to relax and lets momentum of the mass take the body down the track.

Movement

The human body is engineered to utilize a series of lever systems (third class) where force acts between the axis and the resistance. For any movement to occur, the lever must rotate around its axis. Based on this premise, it is safe to say that the origin of movement is rotary.

Rotary motion simply refers to bodily motion. It is the interaction of physical laws and body levers. For an object to rotate, it must have two different types of forces acting on it at right angles: a centripetal or centrifugal force and tangential force. Centripetal and centrifugal forces cause objects to move toward the point of rotation, known as the axis. The axial or tangential force causes object to move perpendicularly in relation to the radius.

In the human machine, force is closer than resistance to the axis. To illustrate, a sprinter resists the ground while producing movement and force with the thigh. This relationship makes the lever very inefficient because more torque is required for movement. For the sprinter, it is essential that the lever move through the full range of movement fast, requiring a torque (turning force) both forward and backward.

Torque (force X movement arm) contributes to the angular velocity of the lever. If the length of the lever is constant, the lever would oscillate like a pendulum. But because lever length changes so does angular velocity, for any given force. Thus the angular velocity ties the length of the lever produces the linear velocity at the point farthest away from the axis.

Both the arm and leg movement efficiency benefit from the ability to lengthen or shorten levers. By lengthening and shortening the lever, the athlete can change the moment of inertia (resistance to movement). The farther the moment of inertia (mass X radius) is away from the point of rotation, the harder it is to change motion.

With a given amount of force, a shorter lever with the same mass as a longer lever would rotate faster than the longer but would have a mechanical disadvantage. It will therefore take more torque (moment of inertia X angular acceleration) to turn the longer lever than it would to turn the shorter. If no additional turning force is applied to the lever, angular momentum (moment of inertia X angular velocity) is conserved. An increase or decline in the moment of inertia will cause decline or increase in angular velocity respectively. This inverse relationship between the moment of inertia and angular velocity in the conservation of angular velocity in the conservation of angular momentum is one of the keys to great sprinting.

Common Errors

Stressing stride length or stride frequency

Debate on the best way of improving sprint speed focuses on two issues:

increasing stride length versus increasing frequency. We are limited physiologically to the amount of strides than can be performed in a second. It is true that most good sprint athletes have just about the same frequency. So, an athlete with adequate conditioning who takes the longest strides usually wins.

Stressing stride frequency alone results in inefficient sprint technique.

Common knowledge portrays stride frequency as a speed advantage. However, stride frequency differs from stride speed. Stride speed is angular velocity of a stride, while frequency is the number of strides, or impulses, per second. Even if a sprinter has the fastest turnover, without proper force application, stride length will be small. This is because frequency alone does cause linear motion; applying force to the ground does. Proper force application results in stride length and frequency increases.

Stride speed is involuntarily increased by the conservation of angular momentum. Shortening the radius, thus reducing the moment of inertia, results in an increase of angular velocity. The shorting of the lever occurs after the foot breaks contact with the ground. This movement is the response of the forces being applied correctly to the ground and is non-volitional.

Illusion of Speed
There is an illusion of speed when then lever does not go through the full range of motion; each movement looks and feels faster. For example if stride frequency is stressed, an athlete may not allow the hip extend through full range of motion to reap whatever benefits he created from applying force to the ground. Lack of hip extension detracts from momentum and ultimately decreases speed because of inefficiency. But the objective is not to move the lever fast but rather transport the mass down the track in the least time possible. Avoiding full range of motion also sacrifices proper force application.

Leg preactivation: pawing action
Pawing action is actually an illusion resulting from rapid hip extension. Too much voluntary action at the knees and ankles causes a reduction in angular velocity of the hip, which is the prime generator of force. Force causes motion while speed is a measurement of motion.

Cyclic force is applied from the hip (radial force) which results in tangential motion of the foot. At foot placement, the shin should be approximately 90 degrees to the ground (Fig. 5). As the center of mass passes over the point of support, the heel briefly touches the ground and the ankle angle closes. This motion puts the Achilles tendon and calf in a stretch position while the knee is bent, allowing a greater push off force from the ball of the foot. Hips extend in one continuous motion from the knee lift position through the end of the push off with no pauses in hip extension at foot contact.

High knee lift
Please see "Knee action"

Reach and Pull
Running action such as reaching and pulling with the hamstrings has been scientifically proven not to produce the most efficient movement (Weyand et. al. 1998). This running style is inefficient because it does not utilize the stretch reflex, but instead requires more muscle forces and volumes per unit of force applied to the ground (Weyand et al. 1998).

Summary
Scientific research across the world has yet to penetrate the track and field world. Athletes can be better sprinters with scientifically proven sprint technique. Better sprinters require coaches who are willing to learn scientific principles as well as a method of communicating their knowledge to the athlete.

Works Cited

Novacheck, Tom F. The biomechanics of running. *Motion Analysis Laboratory,* Gillette Children's Specialty Healthcare, University of Minnesota. 1998; 77-95.

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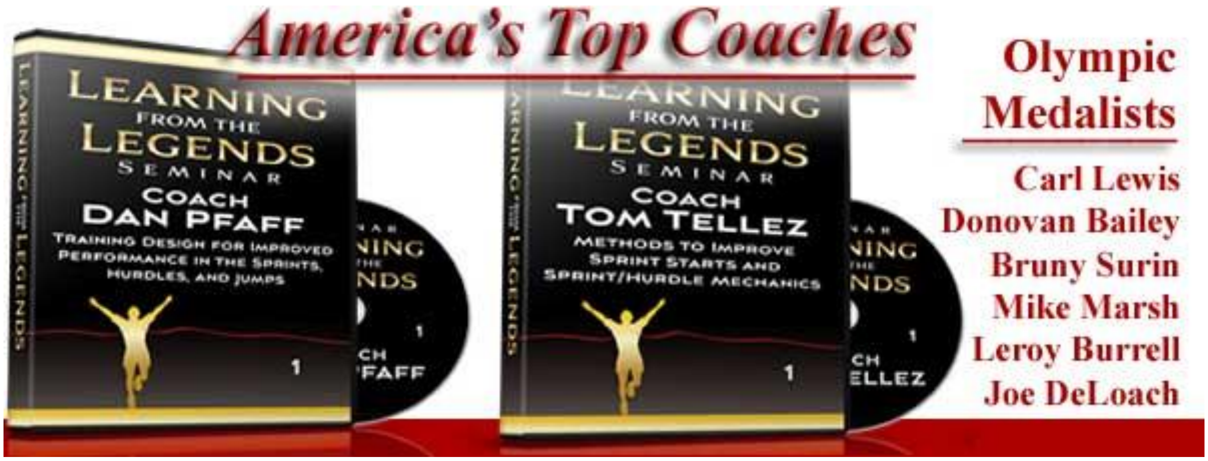
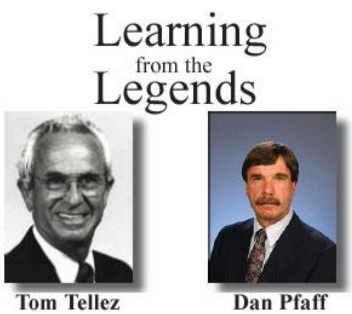
Weyand, Peter G., Deborah B. Sternlight, Matthew J. Bellizzi, and Seth Wright. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology* 89: 1999-2000.

ADDITIONAL RESOURCES

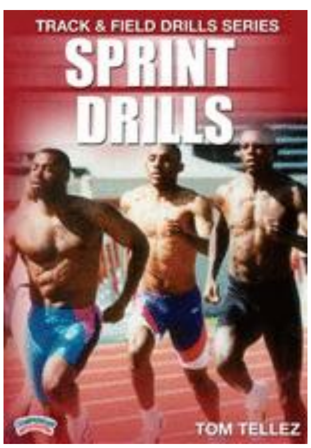




>> [Learning from the Legends]

In these videos, Tom Tellez presents the Sprints, Hurdles and Shot Put. Dan Pfaff presents Sprints, Hurdles and Jumps.

There is an hour long roundtable Q&A period at the end with both coaches, followed by a detailed "Field Event Technique Fixes" by Dan Pfaff. Total length of the lectures: 7.5 hours. [Click here for more information].

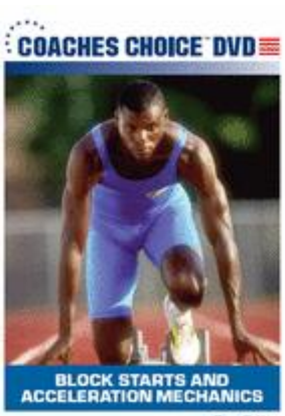


>> [Tom Tellez Sprint Drills]

Tellez discusses and his athletes demonstrate the factors necessary to be a good sprinter (stride frequency x stride length = sprint speed); conditioning drills and dozens of specific drills.

Produced in 1992. 30 minutes.

Available from Amazon.com. [Click here for more information].



>> [Block Starts and Acceleration Mechanics with Tom Tellez]

This DVD presents an overview of the starting and acceleration mechanics. It details the factors that sprint coaches should look for in setting up the starting blocks, the optimal "set" position for an athlete, and what an athlete should do during the acceleration phase of the sprint to maximize performance. Among the topics covered: coming out of the blocks, ideal leg angles in the blocks, acceleration, power vs. speed, and arm stroke. 57 minutes. Available from OnLineSports.com. [Click here for more information.]