Maximal Velocity Sprint Mechanics

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Sprinting is a complex task that places a high neuromuscular demand on the performer and requires high levels of coordinated movement and appropriate sequencing of muscle activations to perform at peak levels. This paper will examine maximal velocity sprint mechanics with particular focus on the primary factors affecting performance, the mechanics associated with those factors, and the causal relationships that occur as a result of optimal sprinting mechanics. Although it is understood that maximum velocity sprinting mechanics cannot be taken out of the context of either the acceleration that preceded it or the biomotor abilities of a given athlete, the following discussion will focus solely on maximal velocity mechanics for the sake of simplicity.

Fundamental Concepts

Before going in to an in-depth discussion of sprinting mechanics we must first examine some fundamental concepts of sprinting performance. First off, speed is a function of stride length and stride frequency. This means that faster speeds can be achieved when either one or both of the two variables are increased. While seemingly simple, the matter is actually considerably more complex. This is because the two variables are actually interdependent in a loosely inverse relationship. That is, for any given runner, as one variable increases the other often decreases. Thus, it is important to find an optimal balance between stride length and stride frequency and not try to artificially manipulate either of the variables as if they were completely independent.

Stride Length and Frequency

The fastest sprinters tend to have stride lengths and stride frequencies as great as 2.6m and 5 steps per second respectively (Mann, 2005). Interestingly, the source of these outstanding characteristics is actually a single attribute. Previous research by Weyand and colleagues (2000) indicates that force applied at ground contact is the most important determinant of running speed. This same research indicated that the speed at which an athlete moves their legs through the air is of little importance. The benefit of greater force application is two-fold. First, greater force application will increase stride length. This benefit is fairly obvious. If all else is equal, greater force applied to the ground will cause a greater displacement of the athlete's body. More simply, a greater distance will be covered with each stride. The second benefit of increased force application is not so obvious and is often overlooked. This benefit is that of increased stride frequency. How, you ask, can increased stride frequency come about as a result of increased force application to the ground? This is where things can get difficult. Stride frequency is comprised of two components: ground contact time and flight time. Research on elite sprinters indicates that the best sprinters spend less time on the ground (Mann, 1986; 2005; Mann & Herman, 1985). This is because the forces they produce are so great that they enter a period of flight more rapidly than their less efficient counterparts. As a result, despite not moving their limbs significantly faster through the air (Weyand et al., 2000), better sprinters tend to have greater stride frequency because they reduce the amount of time they spend on the ground. However, this presents a challenge to an athlete striving to move at increasingly greater speeds. That is, they must produce greater forces over increasingly shorter periods of time.

Force Development and Sprinting

In light of the previous points, to increase running speed, an athlete must increase the force they apply to the ground and do so over increasingly shorter periods of time. Just as important as the magnitude of force application however, is the direction of that force application. For instance, athletes should attempt to minimize horizontal braking forces and maximize vertical propulsive forces. Vertical propulsive forces are important because once momentum has been maximally developed during the acceleration period, the body will tend to keep moving forward at the same speed as long as the internal and external forces acting on the body are balanced. When sufficient vertical forces are generated momentum and velocity are more easily maintained.

With these fundamental concepts in mind, what can be done to maximize sprint performance? Some have suggested that training the biomotor abilities of the athlete should be the only concern for improving sprint speed. This, however, is short-sighted. For optimal development, the biomotor and technical aspects of force production must be addressed. To improve the specific biomotor abilities that will enhance speed, an athlete must increase their physical ability to withstand and produce large forces over short periods of time. This form of training must be high intensity with longer recoveries and an emphasis on quality over volume. However, it is important to remember that force application without regard to the direction of that force will lead to less than ideal results. This is where optimizing the mechanical factors that affect force production comes in to play. It is important that the athlete display appropriate sprinting mechanics to ensure that the forces generated by the neuromuscular system are expressed as greater sprint speed.

Goals of Maximal Velocity Sprinting

There are three primary goals of effective maximal velocity sprinting: preservation of stability, minimization of braking forces, and maximization of vertical propulsive forces. These goals will first be discussed individually and a detailed analysis of the techniques needed to achieve these goals will follow.

Preservation of Stability

The first objective of sprinting mechanics is stability preservation. Stability is crucial to any athletic movement because it ensures that the body is able to move with maximal efficiency. When stability is disrupted, dysfunctional movement patterns and loss of elasticity often result. As with many other aspects of sprint performance, posture is at the root of enhancing stability. Posture refers to the positioning and functional capacity of the core region of the body. Because movement of the limbs largely originate from the core of the body, running with the core stabilized and in proper alignment often ensures optimal movements of the limbs. When this occurs, stability is often preserved.

When the body lacks either proper internal stability or appropriate postural alignment, it often reacts in a reflexive manner to preserve stability. These reactions tend to be very detrimental to sprint performance. To enhance stability, the muscles surrounding the spine should be strong enough to provide a stable origin for movement of the limbs. It is important to note that this stabilization is dynamic in nature rather than static. This means that while the body does act to control movement, small movements will still be present and are actually beneficial to performance. This is especially true of the pelvis. While the general attitude of the pelvis should have a posterior tilt, efficient sprinters exhibit pelvic rotation in all three planes (Novacheck, 1998; Young et al., 2004).

This pelvic rotation can increase stride length by up to 5 cm, which over the course of an entire 100m, may equate to as much as 2.5 meters or a quarter of a second.

Related to postural stabilization, the alignment of an athlete's core is also very important to stability. Ideally, a sprinter's head, neck, and spine should be neutrally aligned and the athlete should display a slight posterior tilt of the pelvis. This posture ensures freedom of movement and facilitates relaxation, both of which enhance elastic energy return from the core and extremity musculature. An upright posture with a posteriorly rotated pelvis also promotes frontside mechanics and limits backside mechanics. Frontside mechanics refers to the actions of the legs that occur in front of the body. Similarly, backside mechanics refers to the actions of the legs that occur behind the body. Greater frontside mechanics and minimized backside mechanics are vitally important to sprinting efficiency.

Minimizing Braking Forces

The second objective of efficient sprinting is minimizing braking forces that the athlete encounters at ground contact. Braking forces refer to those forces which act in the opposite direction of the desired movement. Braking forces experienced in sprinting tend to result in horizontal deceleration. And while these forces are somewhat inevitable and in small magnitudes, actually add to the overall stability of the athlete, all attempts should be made to minimize the magnitude of braking forces experienced by an athlete. The primary cause of excessive braking forces is making ground contact too far in front of the athlete's center of mass (an athlete's center of mass is roughly located in the vicinity of their hips). Ideally, an athlete should minimize the horizontal distance between their center of mass and the point of ground contact. If we relate the cyclic motion of the foot in the sagittal plane to that of a pedal on a bicycle, ground contact should be made as close to the bottom dead center position as possible.

Two scenarios are often the root of excessive braking forces. In many cases, the cause is a willful attempt to artificially increase step length by 'reaching out' with each step. This inevitably makes ground contact occur further away from the bottom dead center position. Also since stride length is primarily a function of force applied at ground contact, stretching out with each step in an attempt to increase stride length may ultimately have the opposite effect due to the horizontal braking forces that such an attempt would introduce.

A second scenario associated with excessive braking forces is instability. When the body experiences instability, it often attempts to regain stability by premature grounding of the swing leg. This often occurs as a result an overemphasis on ‘kicking the butt.’ Premature grounding of the swing leg typically means that the foot will still be moving forward with respect to the body when ground contact is made. This is referred to as excessive positive foot speed and it is potentially disruptive to efficient sprinting because it can increase braking forces at ground contact. Ideally, the foot should be moving backward with respect to the body when touchdown occurs (Mann, 2005). This is often referred to as negative foot speed at ground contact and this movement pattern is highly correlated with increased sprinting speed. It is important to note, however, that it is not advisable to actively ‘paw back’ at the ground in an attempt to increase negative foot speed as this is an unnatural movement pattern that is disruptive to sprinting mechanics and may increase the likelihood of hamstring injuries. Any increases in negative foot speed should be a byproduct of increased frontside mechanics coupled with sufficient flight time. When these factors occur together, they increase the range of motion over which the swing leg has to accelerate down toward the ground and in so doing, increase the likelihood of negative foot speed at ground contact.

Increased Vertical Propulsive Forces

The final objective of effective sprinting is enhancing vertical propulsive forces. Although this point has been discussed previously, it will be examined in greater depth here. Increasing vertical propulsive forces produces a host of benefits. It increases vertical displacement of the athlete which will in turn result in a more effective ground contact position and increased likelihood of negative foot speed on the subsequent ground contact. Finally, increased vertical propulsive force application will enhance leg stiffness which will allow the athlete to better counteract the effects of gravity.

When a sprinter is generating sufficient vertical forces, the athlete’s center of mass will travel in a sinusoidal trajectory in the sagittal plane. The apex of the curve occurs at the midpoint of the flight phase. The low point of the curve occurs just slightly after ground contact is made. The amplitude of the curve is often indicative of the efficiency of the sprinter. Better sprinters tend to have more upward vertical displacement during flight and less downward vertical displacement following ground contact. Lesser sprinters often have difficulty producing sufficient vertical forces and as a result, their hips tend to drop considerably after ground contact. This inevitably lengthens ground contact times and reduces the elastic response of the subsequent push off. As a result of their more efficient force application, better sprinters are distinguished by significantly shorter ground contact times than their less efficient peers.

The second benefit of increased vertical force application is a more effective ground contact position on the subsequent touchdown. Because better athletes tend to have slightly larger vertical displacements during flight they have the time needed to get the swing leg foot close to bottom dead center. When flight time is insufficient, ground contact may be made when the foot is still relatively far in front of a bottom dead center position. This will increase braking forces. When flight time is sufficient, negative foot speed is more likely and ground contact positions closer to bottom dead center are often observed.

The final benefit of increased vertical propulsive forces is increased leg stiffness. Leg stiffness refers to the ability of the legs to act as a spring during contact. Leg stiffness is critically important to maximal velocity sprinting and the maintenance of the momentum developed during the acceleration period of a sprint (Bret et al., 2002; Chelly & Denis, 2001). As an athlete accelerates from a resting position to top end speed the athlete develops momentum along the way. This momentum describes the quantity of motion of the athlete and ensures that in the absence of unbalanced forces the athlete will continue to move at the same speed. There are only two significant external forces which the athlete needs to overcome to maintain their maximal velocity: air resistance and gravity. Air resistance mainly hinders movement in the horizontal direction. Gravity, on the other hand, is an external force that acts in the vertical direction. Interestingly, although sprint performance is assessed by horizontal speed it is gravity that presents more of a limitation to sprint performance. The forces of gravity pull the athlete down toward the ground. When an athlete fails to produce sufficient vertical forces to overcome the downward forces of gravity, they will lack the leg stiffness that is so crucial to maximal velocity sprinting. When an athlete lacks adequate leg stiffness, ground contact times increase significantly and hip height often drops. This inevitably begins a downward spiral of events that lead to the athlete decelerating and losing horizontal momentum. When the athlete produces large vertical forces, ground contact times are shorter and the athlete is able to more rapidly propel themselves back in to flight. This helps to preserve the velocity developed during the acceleration period of the run.

Application of Concepts

Now that the fundamental concepts and goals of sprinting have been discussed, they will now be applied to actual sprinting mechanics. To ensure maximal expression of force as sprint speed, frontside and backside mechanics must be optimized to produce best results. In general, it is safe to say that better sprinters tend to exhibit greater frontside mechanics and minimized backside mechanics. Research on elite sprinters supports this observation (Mann, 1986; 2005; Mann & Hermann, 1985).

Maximizing frontside mechanics produces a cascade of benefits, many of which have already been discussed. Increased frontside mechanics is associated with enhanced stability, minimized braking forces and increased propulsive vertical forces. So how do athletes maximize frontside mechanics and minimize backside mechanics? The answer is actually quite simple. As indicated previously, correct posture promotes front side mechanics while limiting backside mechanics. As is often the case, the actions of the limbs are dictated by the stabilization and alignment of the core. More specifically, the positioning and functional capacity of the limbs is closely related to the positioning and functional capacity of the athlete’s core. When posture is correct, movement of the limbs is often correct. Because of this, posture is of utmost importance to sprint performance.

For efficient sprinting to take place there are some postural prerequisites. The head, neck and spine should be aligned in a neutral position and the pelvis should exhibit a slight posterior tilt. When these traits are present in a sprinter at maximal velocity they will typically display an upright trunk, level head, and maximal hip height. Athletes should strive to exhibit this posture at all times during maximal velocity sprinting.

The following section will examine an efficient sprint stride. To simplify discussion, the sprint stride will be broken down in to a stance phase and a flight phase.

Stance begins with the instant of ground contact and ends at the moment of toe-off. Since the sprint stride should be symmetric and cyclic in nature, the guidelines suggested herein apply to both legs. Special attention will be given to the limbs but always keep in mind that the actions of the limbs are dependent on the proper positioning and stabilization of the core, especially the pelvis. If optimal posture is compromised, attempting to fix the positioning or movement patterns of the limbs will be fruitless. If you fix the cause of a problem, which in many cases will be related to posture, many of the dysfunctional or inappropriate movements of the limbs will automatically disappear.

Ground Contact

As previously indicated, ground contact should be made with the foot as close to bottom dead center as possible. This will help to minimize braking forces. At ground contact, both thighs should be in line with each other and the tibia (shin bone) of the support leg should be approximately perpendicular with the ground. When these positions are not observed, it is almost always due to hyper-lordosis or a ‘butt-out’ posture.

Stance Phase

As the athlete enters the stance phase, they must absorb the impact forces generated at ground contact. Often times, when an athlete lacks adequate postural stability or leg stiffness, they may have difficulty absorbing the forces at ground contact. When an athlete’s hips drop or postural deviations occur during the initial moments of the stance phase, it is often due to the athlete’s failure to prepare for ground contact during the flight phase. Optimal preparation for ground contact will be discussed in the flight phase discussion.

As the body travels over and in front of the support foot, the athlete is no longer absorbing the forces of ground contact and has started to apply vertical and horizontal propulsive forces to the ground. Aggressive forward and upward movement of the swing leg thigh will help to increase the vertical and horizontal propulsive forces applied to the ground due to an action-reaction relationship. When posture is correct, the swing leg foot should step over the support knee and the heel should remain tucked to the buttocks. As the swing leg thigh moves in front of the body, the lower leg should begin to ‘unfold’ and extend at the knee. When ‘unfolding’ of the lower leg occurs prior to this point it is almost always due to excessive backside mechanics.

Toe-Off

Posture should remain upright at the moment of toe-off. For athletes lacking sufficient strength in their postural muscles this can often be a difficult task. The hip of the swing leg should be projected forward slightly and the knee should be high and in front of the body. The ‘high knee’ position of the swing leg places the hamstring and gluteal muscles on stretch which increases their capacity for speed and force development when they accelerate the thigh down toward the ground for the subsequent ground contact. Also, greater frontside mechanics increases the range of motion over which the swing leg can accelerate down toward the ground. In addition to this increased frontside mechanics, better sprinters also exhibit minimized backside mechanics at toe-off. Because of their increased vertical force production, better sprinters tend to toe-off closer to bottom dead center than less efficient sprinters.

Flight Phase

After the athlete breaks contact with the ground they enter the flight phase. Immediately following toe-off, the heel of the push-off leg should be recovered up toward the buttocks. Note, however, that this action is not due to the active contraction of the hamstring. Contrary to the commonly held notion that the athlete should actively ‘kick their butt,’ research evidence suggests that the hamstring muscle is largely silent during this period of the stride cycle (Mann & Hagy, 1980; Thelen et al., 2005a, 2005b). In fact, the knee flexion observed following toe-off is largely a result of the aggressive hip flexion that occurs once the athlete has left the ground.

As sprinters reach the apex of their flight, better athletes are distinguished by greater vertical amplitudes of the previously discussed sinusoidal wave. At this point the ipsilateral leg should have moved to a position completely in front of the body. This is commonly referred to as a ‘high knee’ position. At the end of its forward movement, the thigh should be forcefully accelerated down and back towards the ground. As this occurs, the knee joint will naturally extend and the lower leg will ‘open up.’ There is no need to actively initiate or amplify this movement and doing so could actually be disruptive to efficient sprinting.

As previously indicated, it is very important for athletes to prepare for the stance phase while still in flight. The ground contact period in maximal velocity sprinting is so short (~0.1s) that it is impossible for an athlete to adequately produce the necessary forces during the stance phase without preparing the support leg prior to ground contact. There are several conditions which help to prepare the soon-to-be support leg for ground contact.

The ankle joint may be the weakest link in the leg spring system. As such, it is very important that it is stabilized appropriately prior to ground contact. The ankle joint of the soon-to-be support leg should be in a neutral or slightly dorsiflexed position in the final moments of flight. This position provides several benefits. First, when compared to a plantarflexed ankle joint, ground contact will be delayed by a fraction of a second. This gives the soon-to-be support leg foot a few moments longer to move closer to bottom dead center. This reduction could be as great as 2-3cm which is enough to significantly reduce braking forces. The second benefit of a neutral or slightly dorsiflexed foot position is related to the first. A neutral or slightly dorsiflexed foot places the fascial linkages of the posterior anatomy train on stretch. This increased stretch should theoretically produce a faster downward acceleration of the thigh and lower leg. This greater acceleration should produce greater negative foot speed and help to reduce braking forces at ground contact. Finally, a neutral or slightly dorsiflexed position prior to ground contact places the gastroc-soleus muscle complex on stretch which increases its capacity for elastic force production upon ground contact. These benefits combine to ensure that the weakest link of the leg is in the best position possible to resist the affect of gravity at ground contact.

Another effective means of preparing for ground contact is by emphasizing a vertical pushing motion for maximal velocity sprinting. Although in action, the sprinting motion is a combination of pushing (at the knee joint) and pulling (at the hip joint), anecdotal evidence suggests that it is more beneficial to focus on the vertical pushing aspect of the motion. Emphasizing vertical pushes will ensure that the athlete actively accelerates their thigh down toward the ground during the flight phase and will increase leg stiffness once ground contact is made. This will in turn reduce ground contact time and backside mechanics and increase stride frequency and length.

Arm Swing

The role of the arm swing remains a rather controversial topic among sprint coaches. Some believe the arm swing is crucial to performance and significantly contributes to horizontal propulsive forces. A deeper examination, however, reveals that the role of the arms may not be as significant as previously thought and they may serve a different function than previously believed. Research evidence suggests that the arms do not contribute directly to forward movement or horizontal propulsive forces (Hinrichs, 1987). The horizontal force capabilities of the arms are very limited due to the simultaneous forward-backward action of contralateral arms. That is, although the forward swinging arm has the ability to generate horizontal propulsive forces, any benefit is cancelled out by the opposite action of the contralateral arm moving backwards.

The arm swing does, however, serve two important roles. The first of these is to counterbalance the rotary momentum of the legs (Hinrichs et al., 1987; Mann & Hermann, 1985). If it were not for the action of the arms, an athlete would not be able to control the rotation of their trunk caused by the unilateral action of the legs. The second role that the arm swing serves is to enhance vertical propulsive forces. Research evidence indicates that the arms may contribute up to 10% of the total vertical propulsive forces an athlete is capable of applying to the ground (Hinrichs, 1987). This is because unlike the spatial phase difference of the arm swing in the forward-backward direction, both arms are synchronized in their upward and downward movement. As a result, there is no cancellation of their affect in the vertical direction and the synchronized upward movement of both arms is able to contribute to the vertical propulsive forces an athlete can apply to the ground. In light of these considerations, an optimal arm swing is one which is symmetrical and roughly matches the timing and magnitude of movement of the legs. Efficient sprinters exhibit an arm swing that originates from the shoulder and has a flexion and extension action at the shoulder and elbow that is commensurate to the flexion and extension occurring at the ipsilateral shoulder and hip.

Closing Points

Sprint performance is maximized when the largest possible forces are applied in appropriate directions over very short periods of time. From a technical standpoint, an athlete should strive to preserve postural stability, minimize braking forces and increase vertical propulsive forces. Generally speaking, all three of these issues can be addressed by running with optimal posture, increasing frontside mechanics, and minimizing backside mechanics. In addition to these technical points, biomotor training with an emphasis on developing strength, power, and elasticity in the gluteal, quadriceps and hamstring musculature, as well as strength and stability in the muscles of the core, will help to enhance an athlete’s maximal velocity.

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