Neuro-Biomechanics of Maximum Velocity Sprinting

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ABSTRACT

The most widely used technical model of the running stride comprises three phases: the Drive, the Swing and the Lift. However; using this model, and emphasizing the development of strength to meet the aim of applying more force to the ground, many coaches neglect the neuro-physiological aspects of sprinting technique and may limit their athletes' performance in the. Maximum· Velocity Phase of the 100 meters, known as the key to success in the event. A more contemporary model, taught in the IMF Coaches Education and Certification System and demonstrated by the world's fastest sprinters, provides better understanding of high speed running mechanics and the implications for generating and maintaining greater maximum velocity. According to the authors, this model can be developed using six reference points or foci: Body Position, Recovery Mechanics, Transition Phase, Ground Preparation Phase, Ground Phase, and Arm Action. With video captures of former world record holder Asafa Powell (JAM) in competition to illustrate their points, they discuss each of the foci in detail. They also explain how the quality of any phase in the cyclical movement of the sprinting stride is determined by the quality of the phase that immediately precedes it. They conclude by stating that retaining the traditional model limits the performance potential of the athlete.

Introduction

It has been repeatedly demonstrated that the level of velocity attained and maintained during the Maximum Velocity Phase of the race is the factor most highly correlated with performance and success in the 100 meters. Quickly reaching a high velocity and then holding it through the finish line is possible only through a combination of very efficient acceleration and superior execution of high-speed running mechanics.

Aristotle is said to have made the observation that animals move by pushing against the ground beneath them. So the recently touted notion of the importance of the ground phase of the stride cycle in sprinting is not news by any means. Being able to apply more force to the running surface in less time has always been a key aim in sprinting.

For many coaches, the preferred way to accomplish this aim is for the athlete to "get stronger". However, while strength certainly contributes to the capacity to generate power, this approach falls woefully short of explaining how a great amount of force can be generated in the proper direction and through an optimal range of motion in the very short periods of ground contact, often times less than 100 ms, in the sprint stride.

Power is a combination of strength and neuro-muscular coordination (NMC), with NMC representing neuro-physiological concepts such as motor unit recruitment by summation, order and sequence of recruitment, inter and intramuscular coordination and synchronization. Speed, on the other hand, is a combination of power and neuro-muscular coordination again, but here NMC not only applies the above-mentioned physiological constructs but it also follows principles of motor learning, which effect changes in the athlete's technical model. In common coaching parlance NMC is often used, in this later instance, synonymously with technique.

The most widely used technical model of the running stride comprises three phases: the Drive, the Swing and the Lift. It is safe to say that this has been ingrained in most athletes. At the 2008 European Athletics Coaches' Association Congress in Glasgow, Scotland, this long-used conventional model was contrasted with a not so new, but still not widely understood, model of high-speed running that is taught in the International Association of Athletics Federations (IAAF) Coaches Education and Certification System. It was suggested that the use of the Drive-Swing-Lift model places a ceiling on a runner's ability to generate very high velocity in the critical Maximum Velocity Phase of the 100 meters. This speed barrier may limit performances to the low ten-second range for male sprinters.

This article addresses the issue of how athletes can break through this barrier by providing a description of the more contemporary alternative technical model of high-speed running. It is presented in the belief that athletes can achieve consistently faster performances by applying a better understanding of the mechanics of high-speed running and the implications for generating and maintaining greater maximum velocity. This belief is supported by the fact that the model is clearly exhibited by the world's fastest sprinters.

The high-speed running model applies generally to all running and jumping disciplines. There are differences in the specific models used in each event, but they are very few and are related to the velocity. In most cases, they are differences in the speed, intensity and amplitude of the movement.

The six foci of high speed running

The main emphasis in this article is on the 100 meters and in particular on the Maximum Velocity Phase, which represents the portion of the race when the athlete is moving fastest over the ground. In the 100 meters, the athlete is seeking his/her absolute maximum velocity in this part of the race. In longer events, the athlete, at some point in the race, achieves his/her highest speed for that distance, even though it may not be his/her absolute maximum running velocity. It is important to be aware that any velocity between 95 and 100% of the athlete's absolute maximum employs identical mechanics.

If athletes are to change their motor patterns for high-speed running mechanics and thus improve their mechanical efficiency in this key part of the race, they must develop a sound conceptual technical model. The new model must be introduced, rehearsed and refined. It must then be continually reviewed.

In evaluating and teaching high-speed running mechanics, the coach must give the athletes key points on which to concentrate and consciously focus as they learn to re-programme their motor patterns. It is useful to break down the movement in a way that is consistent with a systematic teaching progression. We use six reference points or foci for developing the conceptual technical model, in the teaching progression employed, during video analysis to identify faults and causes, and in making corrections. These six foci are:

1. Body Position - This is the most central focus for changes in the technical model and thus for improving performance. If the athlete cannot execute the correct body position with a high degree of proficiency, it is nearly impossible to optimize the other five foci. Conscious competence in this area must quickly give way to unconscious competence.

2. Recovery Mechanics - This is the first phase of the high-speed running cycle movement. Often thought of as a passive movement and traditionally called the "swing phase", the mechanically efficient recovery of the limb sets up the other phases of the running stride for higher levels of mechanical efficiency.

3. Transition Phase - This is the phase of the running cycle where an abrupt change of direction of a limb must take place. Faults are often easily recognized in this phase, but they are almost always a product of a cause that is 180° on the other side of the stride cycle.

4. Ground Preparation Phase - This is the phase where the athlete must actively prepare the foot and the leg to strike the ground. From the point of view of determining the performance outcome, this is the second most important phase in the running cycle.

5. Ground Phase - This is the most important phase in the running cycle. Once the athlete leaves the ground, the flight path of the centre of mass is unalterable until the next ground force application. Therefore, getting the Ground Phase right is essential.

6. Arm Action - This is the focus that has provoked some of the greatest disagreements between biomechanists and coaches. Biomechanists have contended that the arms balance the forces of the legs to maintain the body in the proper alignment. Coaches on the other hand have promoted that the arms "control the legs" and thus can positively impact performance. Is it possible that both points of view may be correct?

In the following sections, each of these foci will be discussed in detail using video captures of former 100 meters world record holder Asafa Powell (JAM) in competition to illustrate our points.

Body Position

Body position has three distinctly different components: core stabilization, postural repositioning and control, and vertical (longitudinal alignment). Each must be perfectly executed in order to facilitate a highly efficient motor pattern. If one of the three is executed less than optimally, the overall performance will be less than optimal.

Core stabilization

This has become a buzzword (two words, actually) in the human performance industry, and with good reason. Without a stable core, the body segment that comprises the area inferior to the rib cage and superior to, but including, the hip joint, the athlete cannot generate significant ground forces without leaking energy. One must be able to draw-in and brace in this area so that force will not be absorbed in the many articulations that exist in the core.

Draw-in refers to engaging the investing abdominal musculature; the transverses abdominus, internal and external oblique muscles as well as certain segments of the rectus abdominus. The aim is to decrease the volume of the intra-abdominal compartment. Think of making yourself "skinny" so you can button that tight pair of blue jeans you used to wear ten years ago.

Brace refers to stabilising the vertebral column and pelvis not only in the saggittal plane, but also in the frontal and transverse plane. In practice this means two things. The distance from the xyphoid process and the symphonies pubis must remain constant and the vertical alignment of the xypoid process and symphonies pubis must not deviate laterally because of lateral bending in the frontal plane of rotation in the transverse plane.

Postural repositioning and control

This is necessary to place the musculature that crosses the joints of the core in an optimal length-tension relationship. Often, athletes will exhibit an anterior tilt of the pelvis (pelvis looking down) but the objective here is to reposition the pelvis into a neutral position (pelvis looking up) (see Photo 1).

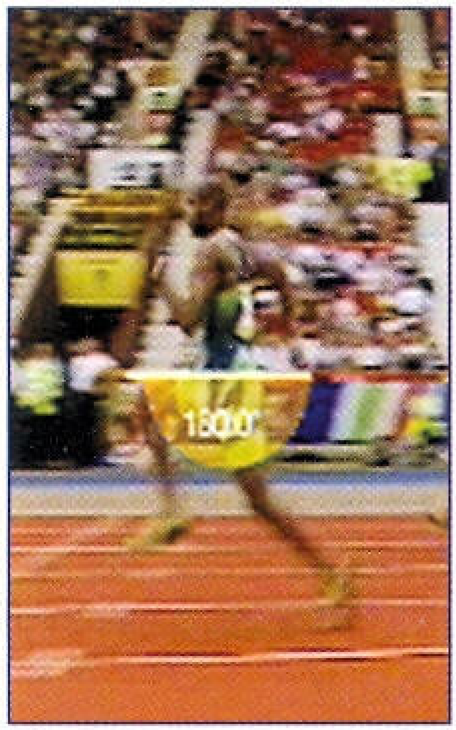


Photo 1

The neutral pelvis places the hip flexors in an ideal length tension relationship to store elastic energy and produce force during thigh recovery. This neutral position also facilitates the initiation of the triple flexor response. Both factors assist in reducing the time required to recover the limb through optimal range of motion. The anterior tilt shortens the hip flexors, rendering them less efficient and switches off the triple flexor response. The consequence is seen in the leg lagging behind the body. This also has implications affecting the efficiency of the ground preparation phase affecting the hip extensors.

Vertical (longitudinal) alignment

With the execution of draw-in and brace and postural repositioning of the pelvis, the athlete must position the shoulders above (or on top of) the hips (see Photo 2).

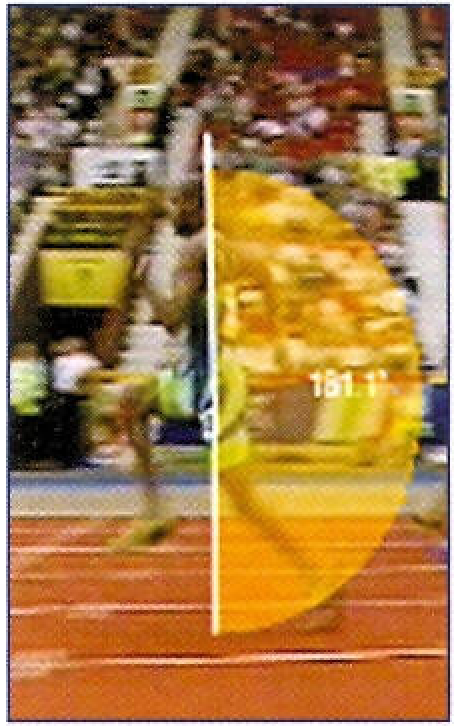


Photo 2

This maintains the optimal length tension relationship of the hip flexors, which then facilitates storing elastic energy and producing force as well as allowing better a triple flexor response. The main fault is as follows: during high-speed running, with the proper draw-in and brace and pelvic repositioning the athlete may still produce a closed chain flexed position at the hip. This shortens the hip flexors. The cause may be that the athlete has a faulty conceptual technical model in that someone may have told him/her that there must be a "forward lean", and this may be how the athlete perceives the movement must be executed. Alternatively, the athlete's hip flexors, either individually or collectively may be hypertonic, thus producing compensation. Finally, the athlete may not be capable of maintaining a draw-in and brace and neutral pelvis without this compensation.

Note that it may be more correct to describe the alignment as "longitudinal". When we discuss acceleration mechanics, the shoulder must fall in alignment with the hip on the power line and is not really vertical to the hip.

Principles governing quality of movement

It is well known that in any cyclical movement, the quality of any phase in the movement is determined by the quality of the phase that immediately precedes it. Let us clearly delineate the difference between the terms "intensity" and "quality". Intensity is a percentage measure of maximum. Quality on the other hand can be discussed as a percentage measure of perfect. When we discuss the phases of the running cycle we must look at the quality or how perfectly and mechanical efficient a movement is executed and not just at the intensity of the movement realized. In the case of our six foci we can also apply this statement to body position. If body position is not perfectly executed, then it is impossible to correctly and perfectly execute any other phase of the cyclical movement.

It is stated above that the most important phase of the running cycle is the Ground Phase. Therefore, it would hold that if your aim is to produce a high-quality Ground Phase then you must have a high-quality Ground Preparation Phase. The aim then becomes the execution of a high-quality Ground Preparation Phase. However, this depends on a perfectly executed Transition Phase, which in turn is predicted by perfectly executed recovery mechanics. (It also holds true that high-quality recovery mechanics must be preceded by a high-quality Ground Phase. This must be the case because the running movement is cyclical.)

Therefore, to develop a teaching progression from a movement analysis standpoint, we must begin by making modifications in the quality of the recovery mechanics, which will in turn positively affect the Transition Phase, the Ground Preparation Phase and ultimately the Ground Phase.

Recovery Mechanics

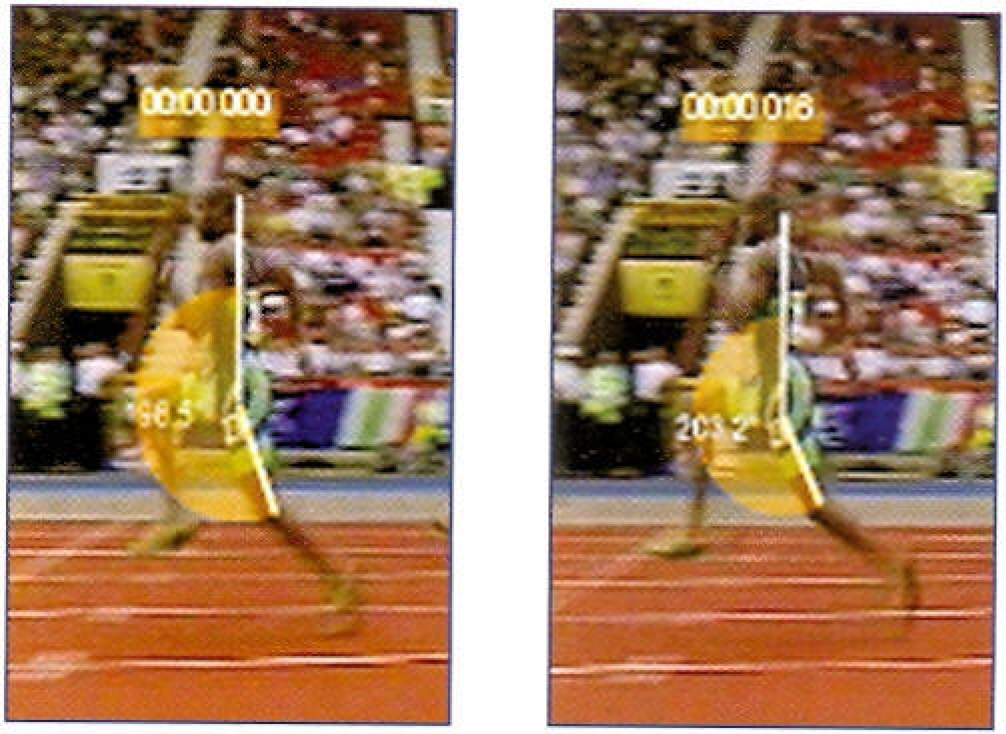
Recovery mechanics comprises two distinct phases: the Residual Phase and the Recovery Phase.

Residual Phase

The Residual Phase begins at take-off and concludes when the thigh begins to accelerate in a positive (forward) direction. One can think of it as what is left over from a high quality force application in the Ground Phase. This phase represents the best opportunity to realize a reduction in the time required to recover the limb through the optimal range of motion.

However, at take-off, the hip joint frequently continues to extend. This is a result of the athlete attempting to continue accelerating the thigh through the entire Ground Phase and not prematurely decelerating the thigh. To achieve one of the two parts of the sprinter's mission statement: "to reduce the amount of time required to recover the limb through an optimal range of motion", the athlete must re-programme the nervous system. Two cues assist the athlete to focus attention. First, maintaining proper body position allows the length-tension relationship to be optimal, thus allowing greater force potential from the hip flexors and a greater efficiency in producing elastic force to initiate thigh flexion.

Second, and more important, is the cue "toe-up". With the proper body position, ankle dorsiflexion allows the initiation of the triple flexor response (see Photo 3 and Photo 4).



Photos 3 and 4

The timing of the dorsiflexion message to the anterior compartment muscles is of critical importance. MOUCHBAHANI et al. demonstrated that the dorsiflexion message was sent sooner in faster sprinters and much later in slower sprinters. The fastest sprinters showed EMG activity over the anterior compartment as early as mid-stance (when the centre of mass is over the base of support). This finding further validates the concept of anticipatory firing or reprogramming the athlete's nervous system to send the dorsiflexion message sooner.

Recovery Phase

The Recovery Phase begins with the positive acceleration of the thigh. The aim here is to maximize thigh acceleration and therefore reduce the amount of time to recover the limb through the optimal range of motion. To this end, use of stored elastic energy in the hip flexors and realizing a low moment of inertia (resistance to angular acceleration) of the thigh are essential.

To minimise the moment of inertia of the thigh, it is critical for the athlete to make the leg as short as possible, as soon as possible. This means that high angular acceleration values must be realized at the knee joint. Dorsiflexion of the ankle joint accomplishes both these tasks. Occurring actively at take-off, dorsiflexion facilitates the triple flexor response. In addition, it facilitates knee flexion by the gastrocnemius. Use of stored elastic energy in the gastrocnemius and its high contraction velocity makes it possible to generate high values of angular acceleration at the knee joint. The result is a short lever as soon as possible.

The ankle remains in dorsiflexion, which maintains a small knee angle throughout the entire Recovery Phase (see Photo 5, Photo 6 and Photo 7).

Photos 5, 6 and 7

Note the relative position of the thighs at the instant of touchdown. In mechanically efficient high-speed running, the knees will be together with the leg folded such that the calf is pressed tightly against the hamstring, at the moment of touchdown (no intra-thigh angle). Reducing the time required in the Residual Phase and the first part of the Recovery Phase represents the only opportunity to reduce air time. This is the case because once touchdown occurs (where the knees should be level) the next ground phase begins (see Photo 8).

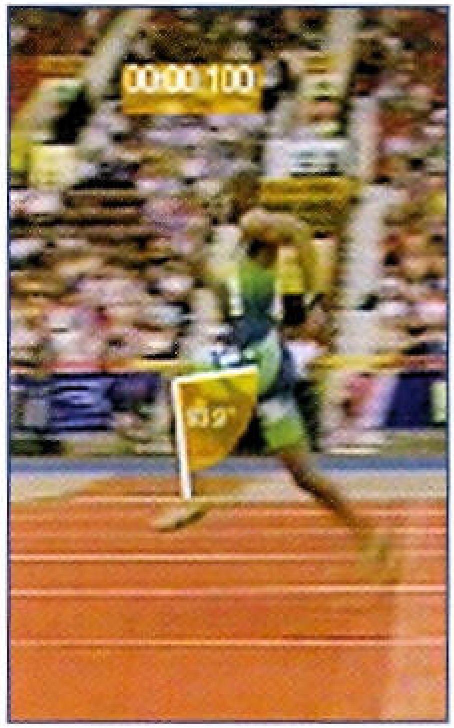


Photo 8

The Recovery Phase ends with an abrupt deceleration of the thigh at optimal hip flexion. The ankle must stay in dorsiflexion and the knee must maintain flexion such that the toe remains posterior to the knee. This insures the lowest moment of inertia values and continued angular acceleration of the thigh until the thigh is blocked. If this position is maintained then the athlete will exhibit an action that has been called "stepping over and around the opposite knee." In events that require lower velocities, athletes will exhibit less intense recovery action, thus stepping over the opposite calf.

Transition Phase

The Transition Phase begins with the abrupt deceleration of the thigh. Blocking of the thigh corresponds with take-off on the other leg. Blocking the thigh allows the sprinter to transfer the momentum generated by rapidly accelerating the mass of the thigh into the body as a whole and therefore unloading the weight of the body. If this is accomplished efficiently, the result is that the force generated at take-off yields a greater vertical and horizontal projection of the centre of mass because the weight of the body is "less". This in turn produces a greater effective stride length (air distance). Transition ends with the negative acceleration of the thigh.

Not infrequently, it appears that a sprinter will float, almost statuesque, with the thigh positioned in the optimal flexion position of the Transition Phase. This prolongation works against reducing the time required to recover the limb through optimal range of motion and return the limb to the ground for the next force application.

Note: a prolonged Transition Phase is often the result of a prolonged Residual Phase. The legs work like scissors. The thigh cannot be accelerated in a negative direction without the thigh of the other leg being accelerated in a positive direction. After all, the quality of the Transition Phase is determined by the quality of the recovery mechanics.

Ground Preparation

Ground preparation is the second most important phase in the running cycle. There is a very high correlation with parameters associated with ground preparation and achieving optimal performance in high-speed running and maintaining a greater percentage of the velocity attained.

Ground preparation begins with the negative acceleration of the thigh. It must be emphasized that the athlete who achieves high angular velocity values through mechanical efficiency does not rely on gravity alone to accelerate the thigh. The high-level sprinter actively engages the gluteals, after experiencing the stretch shortening action of the transition phase, and other hip extensors to actively accelerate the thigh to and through the Ground Phase.

Again, moment of inertia must be minimized. This is accomplished by maintaining total relaxation in the muscles around the knee joint. If the knee is allowed to be loose and unrestricted, the mass and the length of the lower leg do not affect the moment of inertia of the thigh. Once the muscles around the knee contract and stabilize, the limb becomes unitized and the total length and mass of the leg increases the moment of inertia, thus reducing the capacity to accelerate of the thigh.

Through this entire thigh acceleration, the ankle remains dorsiflexed in anticipation of touchdown. By repositioning the foot in dorsiflexion, the athlete aims to turn the foot and ankle into a springboard, storing elastic energy during the ground phase.

As the thigh actively accelerates, the lower leg, because of its own inertia, passively extends at the knees joint. The great American sprint coach Bud Winter described this as "foreleg reach"'. This concept is frequently misinterpreted to be an active extension of the knee joint, rather than a result of high rate of acceleration of the thigh in a negative direction with the musculature around the knee joint relaxed (see Photo 9).

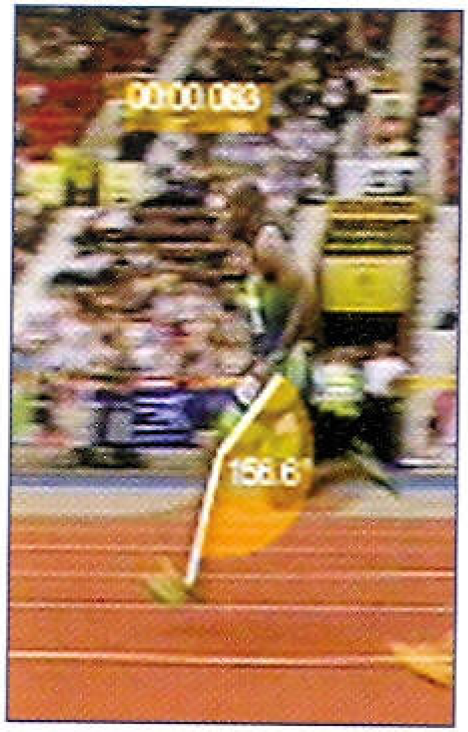


Photo 9

Just before touchdown, at the point of near maximum passive extension of the knees joint, the athlete elicits a maximum co-contraction of the musculature around the knee joint, thus stabilising the knee joint and turning the leg into a unitized "fiberglass vaulting pole" as he/she continues to "grab" the foot under the body. Because angular velocity around the hip joint has been maximized just prior to touchdown, unitizing the leg generates a high negative foot speed. This minimizes breaking forces.

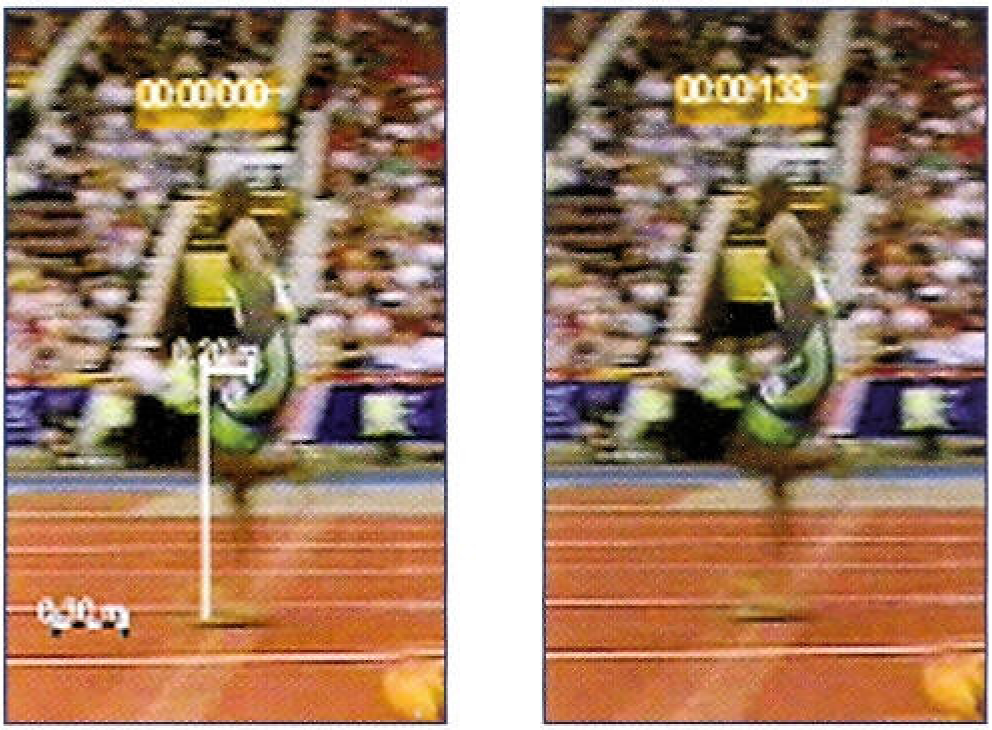
High angular acceleration, which results in high negative foot speed coupled with the high quality recovery mechanics of the other leg yields a small frontside distance (the distance between touchdown of the ball of the foot and the centre of mass). This further minimizes breaking forces.

Ground Phase

The Ground Phase begins at touchdown and has two distinctly different aspects, the Frontside Phase and the Backside Phase. It is important to note that the mechanics occurring in these two phases during highspeed running are very different from the mechanics occurring during the acceleration.

Frontside Phase

The aim in the Frontside Phase is to horizontally displace the centre of mass from touchdown through mid-stance to take-off in as short a time as is possible. During the Frontside Phase in high-level performers, the thigh continues to accelerate at the hip joint while the foot is grounded. Further, because of the co-contraction and stabilization of the knee joint and the small frontside distance, very small amounts of knee joint amortisation should be seen (see Photos 10 and 11).



Photos 10 and 11

This being the case, the athlete must be cued to explode through the track or tear back the track. This is done by continued engagement of the synergistic hamstring muscles in concert with the gluteals. Premature deceleration of the thigh at the hip joint is often due to either a faulty conceptual technical model or insufficient elastic power of the hamstrings and gluteals. It may also be a result of insufficient negative foot speed or excessive frontside distance from a low quality ground preparation phase.

Backside Phase

The Backside Phase begins at mid-stance, when the centre of mass is over the base of support. The cue for the athlete is to continue to push through the ground from the hip. Even though this cue is somewhat incorrect from the point of view of what is happening neuro-biomechanically, it avoids the tendency to prematurely initiate recovery mechanics. This is frequently referred to as rushing the movement.

Interestingly, and somewhat surprisingly, the more important of the two parts of the ground phase in high-speed running is the predominately stored elastic energy. Only 30% of the force is realized in the Backside Phase. When there are greater breaking forces at touchdown, and concomitantly greater deceleration of the centre of mass, the athlete must generate greater forces in the Backside Phase in an attempt to reaccelerate the centre of mass back to the previous speed at take-off. Deceleration of the sprinter results when this is no longer possible (such as during the Speed Maintenance Phase of the 100 meters) in order to have a net change in velocity of zero from touchdown to take-off.

Arm Action

Arm action is like operating a vehicle on a one-way street. You only drive in one direction. The term "drive" in sprinting is related to the application of force by extension at a joint. In this case we are speaking about the shoulder joint. The sprinter positions the hands so the thumbs are up, the palms are facing in and the wrists are loose. The elbow is positioned at a "loose" 90° angle.

The arm is abruptly accelerated by the shoulder extensors. Imagine that your hands are two hammers and the nails are in the wall behind you. Now hammer the nails as rapidly as you can, maintaining the hand position and elbow alignment. What Kevin McNair calls "Hammering the Hand", requires active shoulder extension; however, the recovery of the arm into shoulder flexion is accomplished by the stored elastic energy in the anterior deltoids, pectoralis, and, most importantly,

A common arm action fault is known as dog paddling. This is when the movement of the arms resembles the action of the forelegs of a swimming dog. It results when the forearms are pronated at the radio-ulnar joint. Pronation results in an inhibition of the biceps brachii and a facilitation of the smaller bracheoradialis. The biceps is the most important muscle for storing elastic energy to facilitate arm recovery, so a neutral radio-ulnar joint "turns on" the biceps.

Conclusion

The coaches of the world's fastest sprinters use the technical model of maximum velocity sprinting that is discussed in this article. Many times this has resulted from exposure to the new way of thinking through the coaches education systems of the Central American & Caribbean Athletics Confederation and the IAAF followed by empirical implementation of the model. It is clear that extraordinary results at all levels of sprinter development have been achieved. To retain the traditional technical model is to limit your sprinters' performance potential.

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