Biomechanical aspects of sprint running

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This article is designed to explore some of the biomechanical parameters which make up sprint performance. The aim is that from this outline, some of the training modalities which are most relevant in the preparation of sprint athletes, can be ascertained and integrated into effective speed development programmes.

The ability to run quickly is one of the most sought after motor capabilities in many sports. It is not only vital in many aspects of track and field performance, but a desirable attribute in most game sports. The role of the Strength and Conditioning coach in the development of sprint speed is therefore vital, if performers are to maximise their potential. As part of this process, it seems appropriate to look at the parameters governing sprint performance, in order to provide ideas on what factors can be affected positively, and to guide the selection of exercises to elicit these changes.

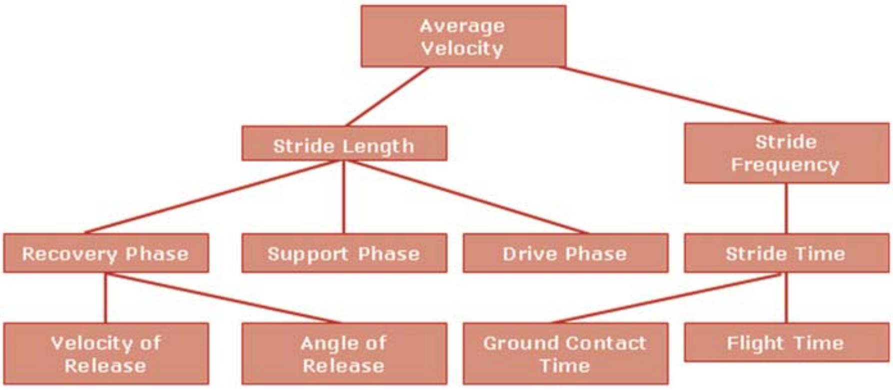

Figure 1: Deterministic model for sprint running

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Figure 1 is a deterministic model outlining the parameters most relevant to sprint running. To simplify the model even more, running speed is the product of stride length x stride frequency[11] (e.g. 2m/stride x 4 strides/s = 8m s^{-1}). So the first question a coach needs to address is: what is your training designed to improve? If stride length or stride frequency are not being addressed within the programme, then it is very unlikely you will improve running velocity. It is important therefore, to have a clear understanding of the factors that affect stride frequency and stride length.

Components of Stride Length

Stride length is made up of 3 phases, the Support Phase, the Drive Phase and the Flight Phase. The Support Phase can be defined as the horizontal distance that the toe of the lead foot is forward of the Centre of Gravity (CoG), at the instant the sprinter lands; the Drive Phase is defined as the horizontal distance that the CoG is forward of the take off foot, at the instant the latter leaves the ground, and lastly the Flight Phase is defined as the horizontal distance that the CoG travels while the runner is in the air.[3]

The Flight Phase is governed by the principles of projectile motion, and the body itself is essentially propelled through the air. While we can do little about air resistance and height of release, the angle of take off can be adjusted, while the velocity of release is of fundamental importance, and will govern how large a stride the sprinter will take. A good release velocity is determined by the ground reaction forces exerted by the athlete, which in turn are the result of the Drive Phase. To maximise this propulsive force, the triple extension of the hip, knee and ankle is vital, while the ability to increase the Drive Phase distance through a good hip extension range of motion will allow these forces to be applied for longer. Also, if applied in the right direction, it will increase the

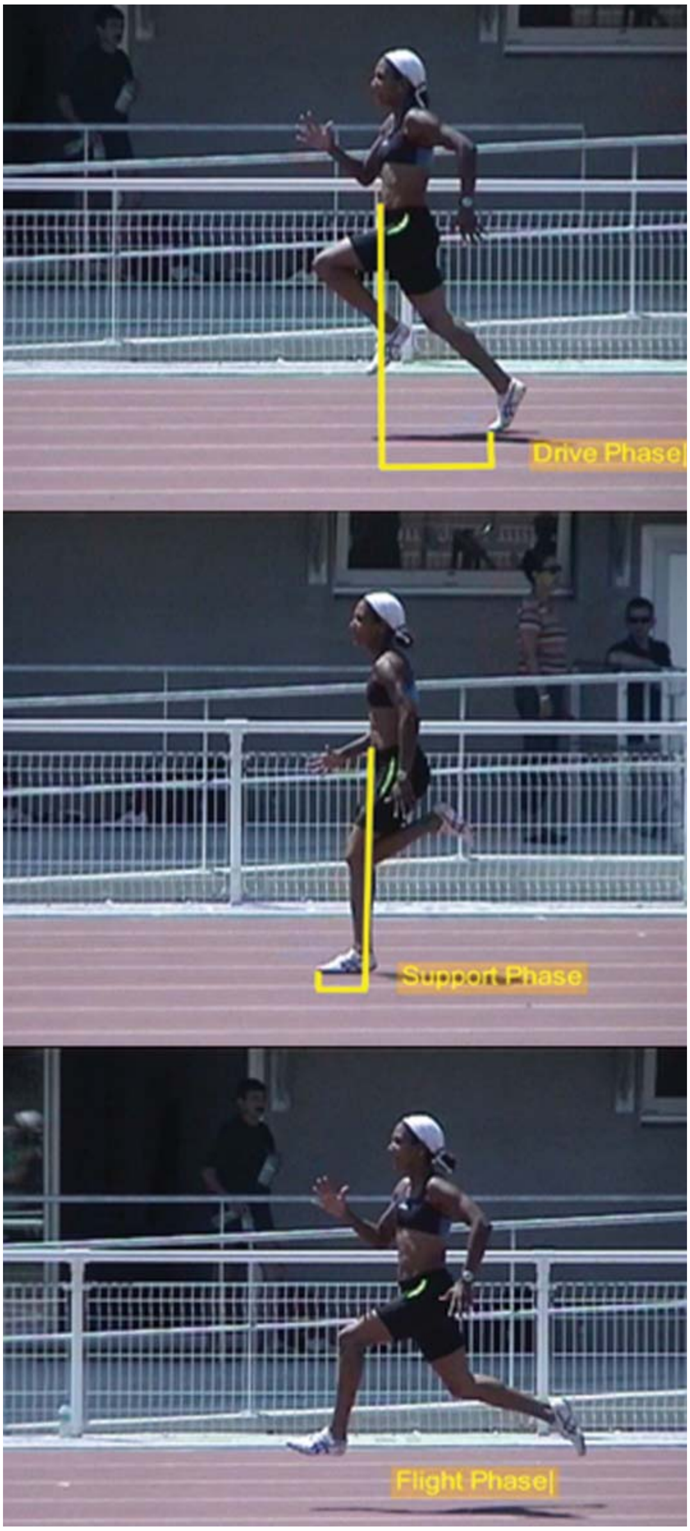

Figure 2. The components of stride length

impulse exerted by the athlete, and therefore their running velocity. The Support Phase needs to be as short as possible; a large Support Phase will mean that foot placement is in front of the athlete's body, and will cause a braking force that the athlete will need to overcome, (remember Newton's 3rd Law: every action has an equal and opposite reaction). This will cause a decrease in running velocity, as stride frequency decreases. The foot needs to be placed under the CoG while travelling backwards to prevent any braking forces, efficiently transfering the momentum built up in the Drive Phase. If forward horizontal reaction is increased, then forward momentum will be increased.

In practice, the Support Phase's braking effect can be limited as follows: the athlete's CoG is moving forward with a horizontal velocity, which is determined the moment the athletes foot leaves the ground. If the CoG's velocity is 10m s^{-1} and the lead leg's foot is moving forward at 2m s^{-1} then the landing foot's velocity will be 12m s^{-1}. Due to this, the direction that the foot is moving will maintain, accelerate or slow an athlete. Because of this, the idea of a pawing action on ground contact at maximum speeds has become popular. However, it needs to be noted that an active pull back of the leg may increase stress on the hamstring. Additionally, while at maximum velocities, it is unlikely the athlete will have time to instigate a pawing action. Instead, by positioning the landing foot under the CoG, the body's own momentum will allow the hip to extend. Therefore the hip can be seen as a pivot, transferring the body's horizontal forward velocity to the leading foot, to maintain that velocity for as long as possible.

Components of Stride Frequency

As running velocity increases, both stride length and stride frequency will increase. However, at faster running speeds, stride frequency will increase to a greater extent than stride length, with faster sprinters exhibiting greater stride frequency than their slower counterparts.[15] Stride frequency is made up of a combination of ground contact and flight time. The ratio between the two will depend on whether the athlete is trying to accelerate or maintain top speed. When starting, ground contact is approximately 67% of the stride frequency time, but decreases to 40-45% at maximum velocity.[1] Short ground contact times are associated with good stride frequency; this is governed primarily by the take off velocity from the previous stride and the ability to transfer that velocity efficiently through the support leg. However, the usefulness of short ground contact times will be lost if the impulse-momentum relationship is not remembered. An athlete therefore needs to increase impulse, (force x time force is applied), in order to increase momentum (acceleration), while the direction that force is applied will indicate the direction of the subsequent acceleration. In practical terms, a more forceful push backwards will propel the athlete faster forwards. This may sound simplistic, but it is interesting to note how many sprint drills actually promote this concept. For example, do high knee drills, (with little horizontal, but a lot of vertical movement), or fast feet, (which have no triple extension and limited horizontal force) really help improve sprint mechanics?

If we examine elite sprinters techniques, it may help us understand the process of sprinters attaining faster stride frequencies. Faster sprinters tend to have smaller hip angles at take off, due to greater hip extension (increasing impulse applied).[14] This will actually cause shorter ground contacts as the high forward velocities seen in elite sprinters will result in the body travelling past the foot more quickly, rather then the result of fast feet. As velocity = displacement/time, therefore, time must = displacement/velocity. In this way, ground contact times will reduce as the body's velocity increases.

Basic Running Technique

The technique employed while sprinting, is vital in order to reach and maintain maximum velocity. To achieve this, there should be a smooth co-ordination of legs, (in a cyclical action), and arms (opposite

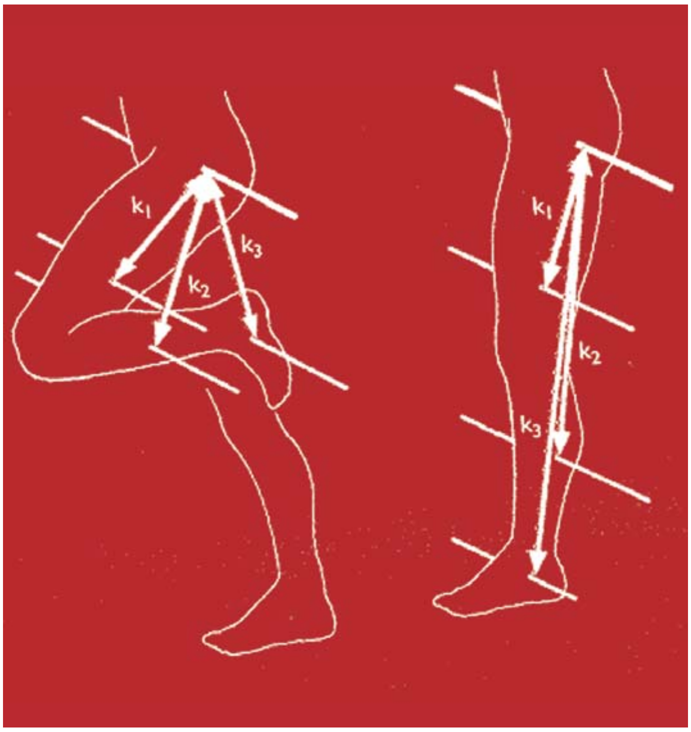

Figure 3: Moment of inertia and the recovery phase

movement to the legs), and attached to a rigid torso, allowing efficient transfer of momentum from stride to stride.

Good running technique is closely linked to the limbs moment of inertia and the conservation of angular momentum. Inertia is the body's tendency to resist acceleration and an increase in mass will increase inertia. However, in angular movement it is a little more complicated. The moment of inertia is not only affected by mass, but also the distribution of mass with respect to the axis of rotation, or the radius of gyration (represented by k in Fig. 3). In this system, inertia decreases if mass is distributed closer to a joints centre of rotation. If we look at the Recovery Phase of the leg in sprinting, as the foot leaves the track, the hip will initially extend and then forcefully rotate forward while the knee rotates backwards. This causes the foot to be positioned as close to the hip as possible, decreasing the legs moment of inertia, and therefore allowing a faster hip flexion action to prepare for the next foot ground contact, (emphasising heel to bum mechanics). In faster sprinters, we generally see a more acute angle between the trunk and thigh, before the knees and hips extend to place the lead limb on the ground.

The arm action in sprinting is important in the conservation of angular momentum.[10] The analogy of Newton's 3rd law, states that every angular action has an equal and opposite angular reaction, while maintaining maximum velocity requires the total angular momentum of the body to remain constant. The greatest angular momentum of the foot is just prior to touch down, (the foot's greatest velocity, with mass distributed furthest from the hip joint), and this needs to be counteracted by the opposite arm rotating backwards. So we see the arm starting in front of the body in a shortened position, (velocity low and angular momentum small), it then extends backwards, increasing velocity and momentum as the arm straightens, allowing the foot's momentum to be counteracted. The faster the hand is travelling backwards, the greater the degree to which the angular momentum of the foot can be tolerated and vice versa. As the leg recovers, the radius of gyration decreases, as does momentum, so the opposite arm will flex as it recovers, as this is needed to counteract less momentum.

The Big Question: How Do We Run Faster?

To sprint more quickly, an athlete needs to increase the torque developed by the hip extensors in order to swing their leg backwards more quickly. Angular acceleration (α) of an object, is proportional to the net torque (τ) acting on that object and inversely proportional to the inertia (I) of the object ($\tau = I\alpha$) or $\alpha = \tau / I$. So angular acceleration increases if torque increases or inertia decreases. Therefore, the muscles around the hip joint produce torque around the hip joint. Increasing this torque (τ) will increase angular velocity (ω) of the leg, and conversely increase linear velocity (υ) of the foot ($\upsilon = \tau\omega$). In the recovery phase, it is important to decrease angular momentum, (achieved by heel to bum recovery), as the hip flexion musculature is relatively weak and requires mass distributed close to the hips axis of rotation in order to effectively move the limb forward. The upper legs CoG in sprinters, is closer to the hips centre of rotation than in other athletes,[13] allowing a decrease in the moment of inertia. Therefore, it is important that the distribution of the legs musculature is attended to. The need for small calves positioned close to the knee, and upper leg musculature positioned close to the hip joint, is vital to allow the fast stride frequencies needed in maximal sprinting. Though this distribution has a genetic component, exercises employed should not build unnecessary bulk at a distance from the joints axis of rotation.

Some Ideas on Training

What physical capabilities does a sprint athlete exhibit when running maximally? Mero *et al.*[15] describes elite sprinters as achieving an average stride length of 2.6m, with a 5Hz stride frequency. Ground contact time varies between 0.08 and 0.1s, while ground reaction forces of 4.6 times body weight are not uncommon. Although these may be ranges for elite track sprinters, it gives an overview of the forces and timings the body needs to cope with while running maximally.

In terms of muscle function, one of the most important factors associated with high intensity performances such as sprinting, is the musculo tendinous unit stiffness (MTU) achieved upon ground contact,[12,16] with a stiff MTU contributing an elastic component to the leg muscles, that, in turn, provides additional power needed to sustain high stride frequencies.[4] Very high forces need to be efficiently transferred from stride to stride to achieve, and maintain, high stride frequencies and therefore running velocity. A lack of MTU stiffness decreases stride frequency,[7] as the landing leg will flex excessively causing a lowering of the bodies CoG, increasing the body's stability, and causing a need to generate more force to propel the body upwards and forwards. Indeed, the role of the knee joint is clearly shown in Johnson & Buckley's[8] work. Power in sprinting is produced in the hip, while the knee maintains the centre of mass height enabling efficient transfer of propulsive power from the hip to the ankle, any knee flexion is going to disturb this process.

Foot position therefore becomes vital; a dorsi flexed ankle in leg recovery will pre-stretch the calf complex, increasing MTU stiffness, helping to promote the stretch shortening cycle (SSC) achieved on ground contact.[2] This can help store strain energy in the passive components of the calf complex, (achilles tendon),[6] decreasing the coupling time between eccentric and concentric actions, allowing a more efficient transfer of momentum. This type of pre-activation can be enhanced by appropriate plyometric exercises. In utilising these exercises, the nature of neural recruitment needs to be noted. Efficiency of movement is enhanced if exercises are performed along the same neural pathway as the sports technique attempting to be enhanced.[9] Therefore, plyometric exercises should be used that have a similar ground contact, posture and limb action to maximal sprinting. It needs to be noted that, many plyometric exercises utlised to develop maximum speed follow a recruitment pattern more akin to the acceleration phase of sprinting, and therefore the aim of the training intervention should always determine the method utlised.

Increasing muscular strength will not only allow greater instantaneous power production, but will also enhance SSC activities[5] by allowing the MTU to be strong enough to cope with high impact forces, by helping increase MTU stiffness. However, again it needs to be remembered that strength adaptations will increase contractile force in the direction of those adaptations; sprinting needs both vertical and horizontal forces, so both components need to be addressed. Specific training will gain a specific response. For example in sprinting, a power output of 20,000-50,000 N s^{-1} achieved at a knee angle of 120-140° occurs, while a power clean achieves a power output between 20,000 and 60,000 N s^{-1} at a knee angle of 120-145°[17] and therefore a specific response is possible. However, it needs to be noted that the hip extension and eccentric stress on the hamstrings, vital in a maximum sprint, may not be fully addressed in this exercise. Coaches should therefore choose their resistance exercises carefully to train the whole of the sprint cycle. Other issues relate to the importance of posture and flexibility, an upright posture that can cope with the large rotational forces caused by the arms and legs is vital for conservation of momentum, therefore an isometrically strong torso, particularly strong in resisting rotational forces, is important. The flexibility around the hip is fundamental, importantly, the ability to extend the hip under load, with an upright body position is vital. Therefore, coaches should ensure that hip extension range is optimal, but also note whether the range is sufficient with the leg straight, body upright and with a force applied through that range.

Lastly, the anthropometric characteristics of a sprinter changes some of the parameters needed to sprint quickly. Sprinters with longer limbs will exhibit greater foot speed compared to short limb athletes at a constant hip angular velocity, because of the advantage in terms of range and speed of motion caused by the increase in lever length. However, the legs mass will be distributed further away from the hip, causing greater angular inertia, and the need to control greater momentum at touch down. In contrast, shorter limbed athletes will have a greater advantage in force production, as short limbs have a mechanical advantage in terms of force production, but slower foot velocities. This means taller sprinters generally need to work on force production to a greater extent than foot speed, while short athletes need to work on foot speed more than force production.

To conclude, sprinting is a vital motor skill for many sports performers, but it is a complex movement pattern to master, influenced by many factors. An understanding of the biomechanical parameters of sprinting is important to understand the technical considerations behind efficient sprinting. This will inform any coach as to what fitness parameters need to be enhanced to produce a faster athlete.

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