# *Speed Training: Linear Acceleration*

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## Introduction

Coaching speed in athletes is a multi-faceted process which requires adequate training of movements, distances, and patterns typically seen in the athlete's sport. Arguably the most important component of sports specific speed training is the development of initial linear acceleration. This initial linear acceleration is when an athlete starts from a stationary position and begins sprinting explosively in a straight line. This movement is seen in nearly every sport and is repeated multiple times throughout most sporting competitions. The purpose of this article is to discuss some of the principles related to linear acceleration which should aid in the coaches' understanding of how to better teach an athlete to improve performance.

## Can Speed Be Trained?

Speed can be trained, but there are only three areas that can be trained that will directly improve an athlete's linear acceleration (2):

- Increasing the number of steps (increasing stride rate) without decreasing the length of each stride.
- Increasing the length of each stride without decreasing stride rate.
- Improving sprinting mechanics which results in less wasted energy and more productive force production and utilization.

One other area which can have an immediate impact on how fast an athlete appears in short distances is the athlete's reaction time. Reaction time is defined as the time from a stimulus (ball, opponent, etc) until the production of force (11). For over 100 years, the accepted figures for simple reaction times for college-age individuals has been about 190 ms (0.19 sec) for light stimuli and about 160 ms (0.16 sec) for sound stimuli (1, 4). However, the fastest athletes in the world consistently have reaction times less than 0.15 seconds (5, 9). In identical events women have been shown to have longer reaction times than men (10). However, reaction time does not correlate well with sprints lasting longer than a few seconds (9), and therefore should only be an important aspect of training after sprinting technique, strength, and power has been developed.

## Basic Physics For Coaching Linear Acceleration

The simple goal of an athlete from a stationary start is to break inertia and move in a forward direction as quickly as possible. For this to be achieved the athlete (usually unknowingly) is relying on four important (bio) mechanical principles. A competent coach should be familiar with these principles and understand how they can be manipulated to help the athlete become a faster performer. These four principles are Newton's three laws (theories) of motion and the kinetic concept of impulse.

***Newton's 1st law: Inertia***

Every object continues in its state of rest or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.

Initiating movement requires the athlete to increase muscle force to help overcome inertia

***Newton's 2nd law: Acceleration***

The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

$$\text{Force} = \text{Mass X Acceleration}$$

$$\text{Acceleration} = \text{Force/Mass}$$

As an athlete's mass does not change during movement, the improvement in speed is obtained by manipulating force and acceleration.

***Newton's 3rd law: Action-Reaction***

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first. "For every action, there is an equal and opposite reaction."

The force of the athlete pushing hard into the ground, and the reactionary force of the ground pushing equal force in the opposite direction, leads to the athlete's forward horizontal movement.

***Impulse: Force X Time***

The impulse-momentum relationship is probably the most important component in the movement from a stationary position.

$$\text{Force} = \text{Mass X Acceleration}$$

$$\text{Acceleration} = (\text{Velocity}_{\text{final}} - \text{Velocity}_{\text{initial}}) / \text{Time}$$

Therefore,

$$\text{Force} = \text{Mass X } (\text{Velocity}_{\text{final}} - \text{Velocity}_{\text{initial}}) / \text{Time}$$

$$\text{Or, Force} = (\text{Mass X Velocity} - \text{Mass X Velocity}_{\text{initial}})/\text{Time}$$

Hence,

$$\text{FORCE X TIME (IMPULSE)} = (\text{MASS X VELOCITY}_{\text{final}}) - (\text{ MASS X VELOCITY}_{\text{initial}})$$

This equation states that the impulse is equal to the change in momentum that it produces. When an athlete is in an athletic starting position (no movement), the velocityinitial is zero, and mass remains constant. Therefore, the horizontal displacement divided by the time (velocity) of the athlete, is directly proportional to the magnitude of the impulse exerted on the ground and consequent reaction (Newton's 3nd Law). To maximize impulse, initial force into the ground must be large, and the time on the ground needs to be small. Impulse represents the average amount of force serving to propel the athlete, and the time over which this force acts. This is why power (force X distance/time) is such an important training component to help develop faster athletes (2, 5, 6, 13).

## Acceleration

After breaking inertia, the athlete's aim is to increase acceleration. Faster athletes have greater force production and horizontal velocity than the slower athletes during the last contact points on the ground (10). This means that the power output at the last stage of ground contact is higher in faster athletes and this is an area that coaches should focus on during training sessions.

Sprinting technique during an athlete's acceleration is vastly different to that of an athlete who is running at or near maximum velocity (7, 13). Most competitive athletes do not reach maximum velocity until 40 – 60 meters (depending on training level/genetic ability). In most sports, athletes do not run in a straight line for 40 – 60 meters; therefore, maximum velocity should be less of a focus for most sports specific speed training programs, with acceleration training being the most important component of speed training. Also, the majority of acceleration (change in velocity) takes place within the first 25 meters (6) (see figure 1).

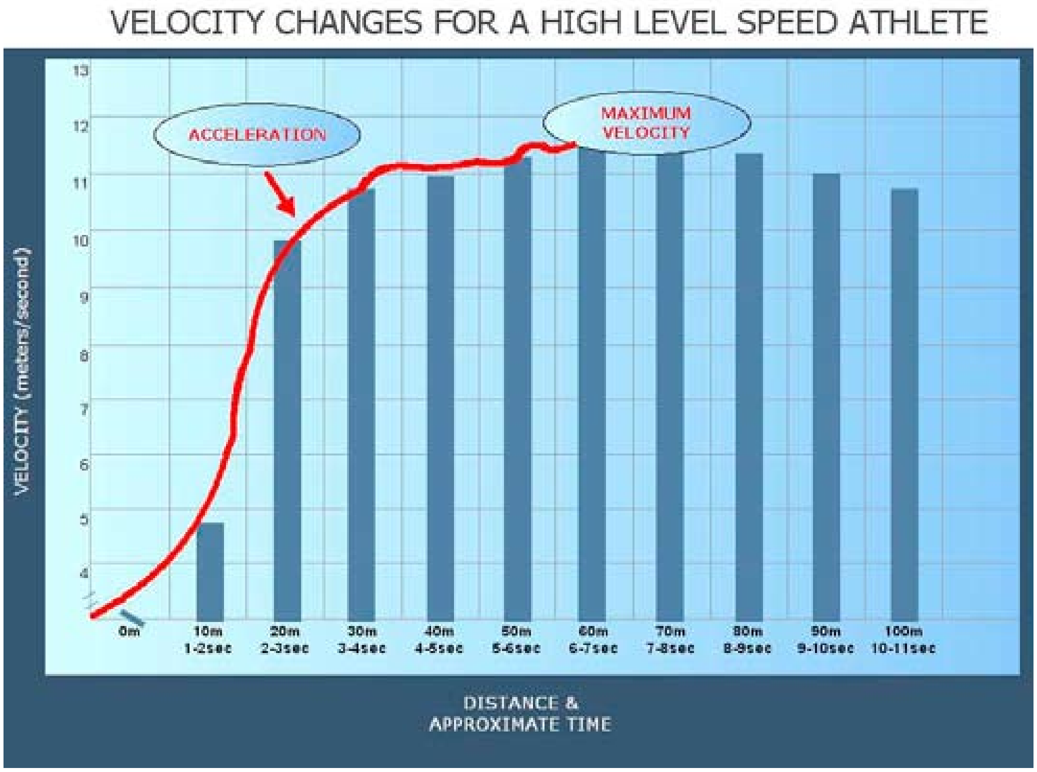


Figure 1: Typical velocity changes for a high level speed athlete

## Acceleration Technique

The acceleration phase of sprint running is characterized by a relatively longer stance phase as the runner endeavors to generate velocity (8). During the first few strides of acceleration the athlete's center of gravity undergoes a posterior shift, from an anterior position at foot strike to a position posterior to the point of foot strike and as the athlete's velocity increases the center of gravity gradually moves forward as the athlete's body becomes more upright (10). The goal of the first few strides of acceleration is to increase body lean (see Figure 2) as this allows for longer strides without sacrificing acceleration.

## Phases of Each Sprint Cycle

During each sprinting stride an athlete travels through phases. Different coaches have used different words to describe these phases. The simplest description of a sprint stride has been to break the stride into the stance phase and the swing phase. The time that the foot is in contact with the ground during the sprint cycle is termed the stance phase and the swing phase is from the ipsilateral foot strike to ipsilateral toe-off (3). A more complex breakdown of the sprint stride can have each sprint stride partitioned into six distinct phases (12). The quality of each phase is determined by the preceding phase.

***Residual Phase***: The moment the right toe leaves the ground until the right thigh comes forward (via hip flexion).

***Recovery Phase (a.k.a "Swing Phase")***: The moment the right thigh comes forward (via hip flexion) until the right thigh stops ("blocking"). This takes place when the hip angle is between 120° to 90°.

***Transition Phase:*** From the moment the right thigh stops (end of recovery phase) until the right thigh starts accelerating toward the ground (via hip extension).

***Ground Preparation:*** From the end of the transition phase (point of first acceleration of the right leg toward ground) until the right foot touches the ground. The goal of this phase is to minimize braking forces before the ground contact.

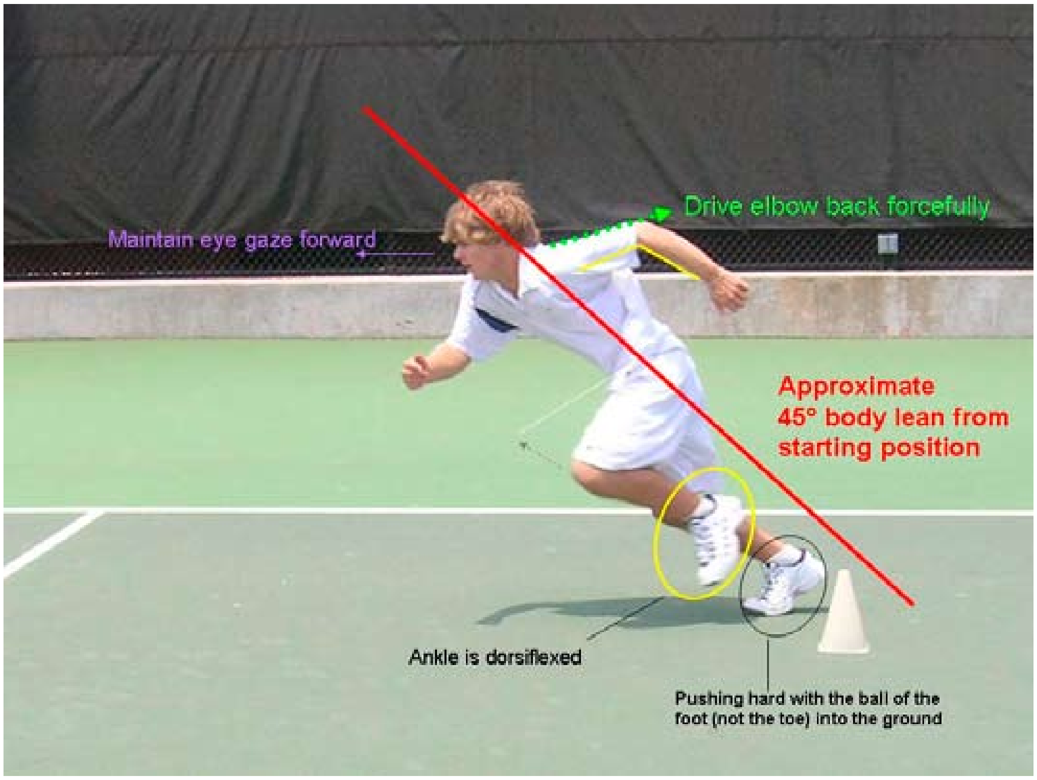


**Figure 2: First step position from a stationary start (initial acceleration)**

*Ground Phase (divided into two separate phases):*

**Frontside Ground Phase:** From the instant the foot touches the ground until the body's center of mass is over the ground contact point of the front foot.

**Backside Ground Phase:** From the midstance of support over the front foot (end of frontside ground phase) until the foot leaves the ground into the next residual phase and the cycle continues.

As the sprint stride is a cyclical motion, muscles must alternate between lengthening and shortening muscle actions. Hip extension from ground phase through the residual phase is vital for horizontal displacement, which requires hamstring and glute contractions (7).

## Arm Action

The arms work in opposition to the legs, with the left arm (via shoulder flexion) and right leg (via hip flexion) coming forward as the right arm (via shoulder extension) and left leg (via hip extension) go backwards. The arm swing is initiated and controlled from the shoulder girdle. The trapezius should be relaxed and the relative elbow angles of both arms should be maintained at approximately 90° angle throughout each arm swing. The arm movement should stay close to the body, starting parallel to the iliac crest (hip), within 10cm of iliac crest, and moving up parallel to the nose.

## Summary & Practical Application

The following chart is designed to assist coaches in the training of linear acceleration with their athletes. The chart below summarizes how the optimum aspects of linear sprint running changes as an athlete increases their velocity (6).

| | |
|---|---|
| **Stride Length**<br><br>short→medium/long and maintain<br><br>1.30m→1.47m→2.35m (maximum velocity) | Initially, short strides increase to moderate to longer strides throughout the acceleration stage. Once maximum velocity is reached (50 – 70 meters), stride length should be maintained (and not increased). |
| **Total Stride Time**<br><br>relatively constant throughout the race<br><br>range from 0.21 seconds to 0.26 seconds | Total stride time is the combination of ground contact time and flight time (time in air). Total stride time is relatively constant; however, the percentage of time spent during ground contact and flight time, is vastly different during the different stages of the race. |
| **Ground Contact Time**<br><br>long→short→shorter and maintain<br><br>0.22 seconds→0.11 seconds→0.09 seconds | The amount of time the foot is in contact with ground. Ground contact time moves from long ground contacts at the beginning of acceleration (as a mechanism to generate force into the ground) to very short ground contacts as maximum velocity is reached. |
| **Flight Time**<br><br>short→longer→longest<br><br>0.03 seconds→0.08 seconds→0.119 seconds | The time during each stride spent in the air. Flight time is short during the first few strides of acceleration, but becomes longer as velocity increases. |
| **Shin Angle To Ground**<br><br>small→medium→medium and maintain | The angle between the anterior shaft of the tibia and the ground starts at a very small angle. As stride length increases and body position changes (more upright) as velocity increases, the shin angle to the ground increases to between 70 – 85°. |
| **Velocity**<br><br>slow→fast→fastest→fast<br><br>(0 m/s→7 m/s →10 m/s→12 m/s) | Slow at the onset of the race and increases rapidly over the first 20 meters. Velocity increases more gradually for the next 30 – 40 meters until maximum velocity is reached, between 50 – 70 meters. Once maximum velocity is reached it can only be maintained for approximately 10 – 20 meters. |
| **Stride Frequency** | Slow stride frequency at the beginning of the race increases rapidly as velocity increases. |
| **Heel Height From The Ground** | This is directly related to the height of knee lift throughout each stride. At the beginning of acceleration, the heel height and knee height are rather low. As the athlete increases their velocity the heel and knee height increase throughout the acceleration period. |

*Chart adapted with permission (6)*

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